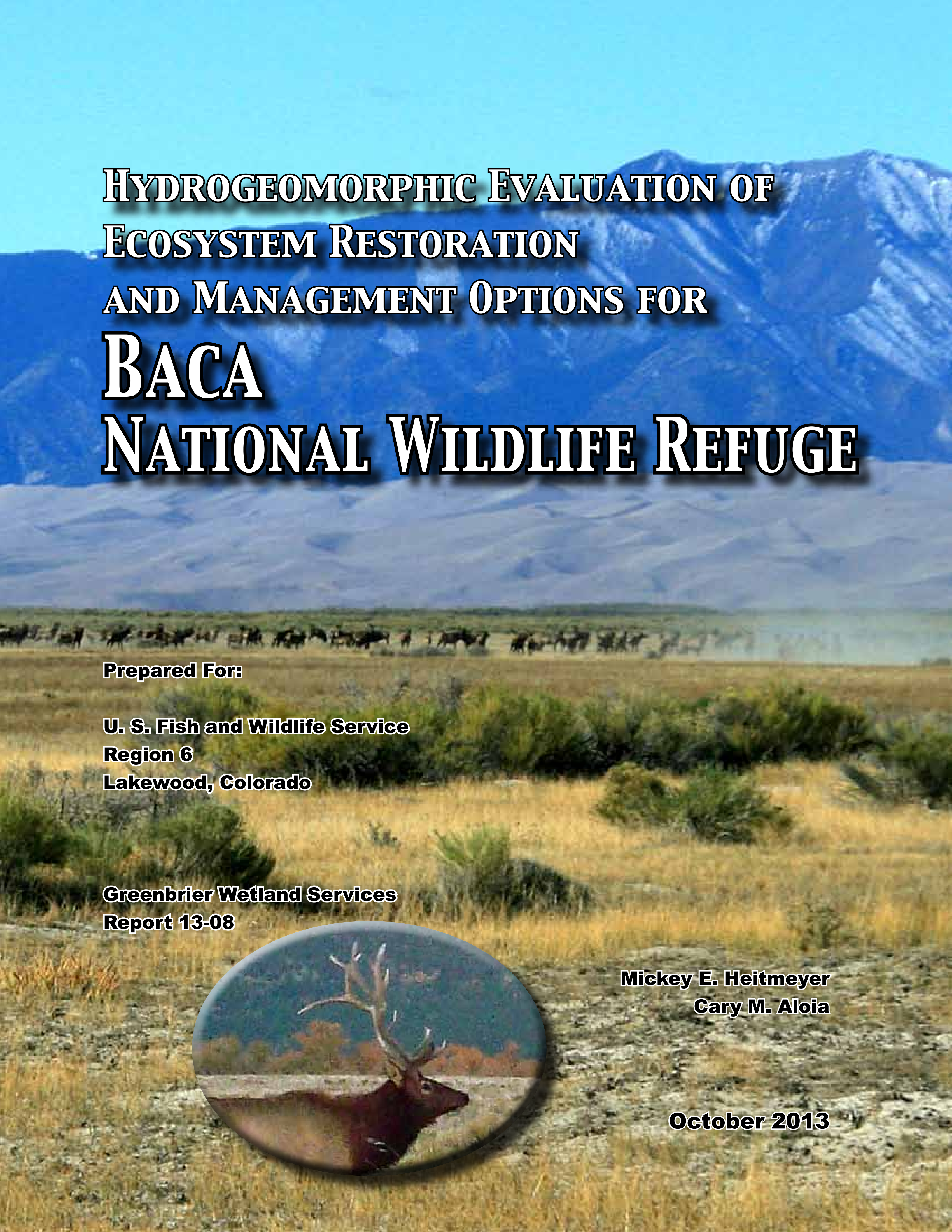

Hydrogeomorphic Evaluation of Ecosystem Restoration and Management Options for Baca National Wildlife Refuge

Prepared For:

U. S. Fish and Wildlife Service
Region 6
Lakewood, Colorado

Greenbrier Wetland Services
Report 13-08

Mickey E. Heitmeyer
Cary M. Aloia

October 2013

HYDROGEOMORPHIC EVALUATION OF ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS FOR BACA NATIONAL WILDLIFE REFUGE

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Cary Aloia

EXECUTIVE SUMMARY

This report provides a hydrogeomorphic (HGM) evaluation of ecosystem restoration and management options for Baca National Wildlife Refuge (NWR) in the eastern portion of the San Luis Valley (SLV) in south-central Colorado. Baca NWR currently contains 85,942 acres and was authorized by Congress in 2000 as part of the Great Sand Dunes National Park and Preserve Act. Baca NWR is located at the base of the Sangre de Cristo Mountain Foothills in the Closed Basin of the SLV and contains a large portion of the regionally unique eolian sand sheet, portions of mountain alluvial fans, and several creeks that originate in the Sangre de Cristo Mountains and discharge into San Luis Creek. Saguache and La Garita creeks that originate in the San Juan Mountains to the west also flow into San Luis Creek and part of Baca NWR lies within the area referred to as the Upper Sump area of the Closed Basin where creek flows merge and contain numerous playa type wetlands along San Luis Creek.

Many land and water changes have occurred throughout the SLV, and at Baca NWR, since European settlement. Many lands now contained in Baca NWR formerly were part of the Luis Maria Baca No. 4 Land Grant of 1860, which was granted by the U.S. government to the heirs of Baca after the Mexican American War. Most of the water-control and road infrastructure present on Baca NWR today was initially constructed by Alfred Collins for his beef cattle operation on the ranch. This water-control infrastructure was used to divert water from the many local creeks for production of pasture and hay. The Presettlement vegetation of the ranch contained interspersed salt desert shrub, grasslands, wet meadows, narrow riparian woodland along some creek channels, and small and larger playa wetlands in the San Luis Creek floodplain and the Upper Sump region.

A specifically defined wildlife conservation mission for Baca NWR was not immediately established at acquisition; however a Conceptual Management Plan was developed in 2005, which adopted the national mission of the NWR system. In 2009, the purpose of Baca NWR was amended "to restore, enhance, and maintain wetland, upland, riparian, and other habitats for wildlife, plants, and fish species that are native to the San Luis Valley" by the Omnibus Appropriations Act. This Act also specified certain requirements to emphasize migratory birds, consider the refuge in broader SLV conservation efforts, and to use decreed water rights consistent with historic uses. In 2011, the USFWS initiated a new CCP planning process for the SLV NWR Complex, including Baca NWR. This HGM report provides information to support the new CCP and subsequent management of Baca NWR with the following objectives:

1. Describe the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Baca NWR region.

2. Document changes in the Baca NWR ecosystem from the Presettlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.

3. Identify restoration and management options and ecological attributes needed to restore specific habitats and conditions within the Baca NWR region.

Information was obtained on historical and contemporary geology and geomorphology, soils, topography, climate and hydrology, and plant animal communities of the Baca NWR region. The surficial geomorphology of Baca NWR is dominated by Quaternary-age deposits. Wind moved eolian sediments from an area just east of the historic Rio Grande alluvial fan in the southwest part of the SLV northeast towards Baca NWR and the Great Sand Dunes National Park during drought periods. Eolian surfaces were deflated and transitioned from a sand sheet to a dune field, and eventually to sand ramps on what is now the Park. This eolian sand covers part of Baca NWR. The erosion of these sand particle deposits occurred in what is described as the Upper and Lower Sump areas, where a heterogeneous playa and dry lake wetland complex occurs along the axis of the Closed Basin in the western portion of Baca NWR. The surficial geomorphology of Baca NWR also has been influenced by the many creeks that flow into the Upper Sump area.

Three major soil-landform associations with 37 distinct soil types are present on the refuge. The Space City-Cotopaxi (SCC) association is present in the eastern and southern parts of the refuge with deep soils that are level to moderately sloping in dune-like topography that is intersected by intermittent creeks. The Space City soil series covers about 22% of the refuge. The SCC soils historically supported upland shrub and grassland communities. The Big Blue-Gerrard (BBG) association is commonly mapped to floodplains along creeks on Baca NWR and consists of clay loam or loamy surfaces. These soils have seasonally high water tables and may be flooded for short periods; this association occurs within the Upper Sump area where most playa lakes occur. The Hooper-Hagna-Hapney (HHH) association includes deep soils with saline or alkali characteristics on nearly level surfaces of floodplains and terraces.

The climate of the SLV is semi-arid, with cold winters and moderate summers. The Great Sand Dunes National Park on the southeast side of Baca NWR receives about 11 inches of precipitation per year, with 60% occurring as rain in July and August. Long-term precipitation data suggest that alternating low and high yearly precipitation patterns recur at about 20- to 30-year intervals. Historically, the Closed Basin of the SLV, including Baca NWR, received surface water inputs from mountain creeks and onsite precipitation. Creeks originating from the Sangre de Cristo Mountains that flowed directly onto Baca NWR include

San Luis, San Isabel, North and South Crestone, Willow, Cottonwood, Deadman, and Spanish Creeks. Some flow of Sand Creek entered the refuge at the very southern end of the refuge. Seasonal flow in these creeks historically was bimodal with increased flow in spring following snowmelt and again in July and August when monsoonal rains caused flash flooding in creeks. Certain creeks also had flows onto refuge areas in winter when temperatures were above average and snowmelt occurred. Saguache and La Garita Creeks flowed into San Luis Creek from the western San Juan Mountains. Two main aquifers, the shallow unconfined and the deeper confined, underlie the SLV.

Baca NWR historically contained a diverse mosaic of vegetation communities. Upland salt desert shrub communities were present on mountain alluvial fans and were interspersed with grasslands on lower elevations of the fans. Grasslands were present down to the edges of the Upper Sump and the San Luis Creek floodplain and wet meadow and grasslands habitat was present along seasonally inundated creek floodplains. Narrow, and apparently limited, riparian woodland was present along at least the upper elevation reaches of creeks originating from the Sangre de Cristo Mountains. Many large and small playa wetland basins were present in the Upper Sump and the San Luis Creek floodplain. An HGM matrix of relationships of major plant communities to geomorphic surface, soil, general topographic position, and hydrology at Baca NWR was developed. The ecological attributes identified in the HGM matrix were used to make a model map of the potential distribution of historical vegetation communities at Baca NWR to provide some guidance to future community restoration activities.

The historical and more contemporary changes to the Baca NWR ecosystem are chronicled in the report including discussion of early settlement and land use changes, contemporary hydrologic and vegetation community changes, and refuge development and management. The primary changes at Baca NWR that need to be addressed for future restoration and management goals are: 1) alterations to distribution, chronology, and abundance of surface water entering the refuge; 2) diminished groundwater levels from groundwater well pumping including the Closed Basin Project; 3) conversion of upland shrub and grassland habitats in some areas to artificially managed wet meadows or greasewood dominated areas that have higher salinities; and 4) alteration to local topography. A major challenge for future management of Baca NWR will be to determine how to restore and emulate natural water regimes and water flow pathways/patterns on the refuge to assist efforts to restore and provide critical habitats and communities to native wildlife within constraints of water rights, Closed Basin Project authorizing legislation, refuge establishment purposes, and USFWS policies.

Fortunately, much of the physical integrity and presence of native communities and associated resources remain intact at Baca NWR. This HGM report helps identify certain ecosystem degradations that have compromised or somewhat altered important ecological processes that created and sustained the Baca ecosystem, such changed amounts and distribution of surface and groundwater. Clearly, certain conservation actions activities that can help restore or mediate important processes will require activities and cooperation outside the boundaries of the refuge by many entities. Other important conservation actions can occur more locally within the refuge boundary.

Based on information obtained and evaluated in this HGM study, we believe that future restoration and management of Baca NWR should consider the following goals where possible:

1. Restore natural water flow pathways and creek/floodplain processes where possible in Crestone, Cottonwood, Willow, Spanish, and Deadman creeks.

2. Restore natural hydrological regimes in playa wetland systems throughout the historic San Luis Creek drainage.

3. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible.

4. Manage herbivory in riparian areas, wet meadows, grasslands, and shrublands to emulate natural processes and conditions.

Specific recommendations for each of the above ecosystem restoration and management option goals are provided in the report.

For goal #1 they include:

- Restore water distribution to historical drainages and allow creeks to overflow banks along with managing water delivery to improve water flow through natural drainages.
- Restore natural creek bed elevations in areas where creek beds have been incised.
- Manage water in drainages in wet years to provide surface flows to San Luis Creek and playa wetlands.
- Restrict new development of water-control infrastructure that would compromise natural water flows.
- Prevent ponding of water along roads and levees and evaluate roads to determine if cooperative efforts can remove or restructure roads and associated structures to promote natural sheetflow and prevent water impoundment.
- Work with the U.S. Bureau of Reclamation to restrict pumping of shallow unconfined wells that locally diminish groundwater levels that negatively impact grasslands, particularly those areas adjacent to creek drainages.
- Remove inactive water-control structures along creeks.

- Seek restoration of incised stream bed levels at a refuge-wide scale based on specific stream sites and refuge priorities.

Specific recommendations for Goal #2 include:

- Manage playa wetlands on clay loam soils within the Upper Sump region.
- Allow playa basins to dry, including larger ones such as Weisman Lake, to mimic natural water dynamics.
- Mimic natural seasonal water regimes in playas for late spring and early summer flooding and fall drawdowns.
- Allow natural flow of water into playas during wet years.
- Remove water-control infrastructure in playas that promotes prolonged impoundment of water and that are restricting flow through playas, impounding water in the historic San Luis Creek channel, or that are preventing natural flow into and through this region.

Specific recommendations for Goal #3 include:

- Restore and manage wet meadows on Vastine, Hagga, Hapney, and Schrader soil types adjacent to creek channels on alluvial fans.
- Manage water regimes in wet meadows to emulate spring inputs of water and long-term wet vs. dry regimes. Vary annual flooding regimes of wetlands among years to emulate periods of natural drought or more extended flooding at 5-7 year intervals of peak-to-peak and low-to-low patterns.
- Allow flash flood events in late summer and early fall that are caused by monsoonal rain events to access wet meadows.
- Restore grasslands in loamy sand or sandy loam soil locations adjacent to and in-between creek drainages on alluvial fans.

- Prevent artificial impoundment of water in areas mapped as HHH and SCC soil associations on alluvial fans. These areas are more suited for upland shrub communities.
- Restore former riparian woodland areas along the higher elevation reaches of Deadman Creek.
- Control invasive plant species and promote re-establishment of native species composition, diversity, and distribution.

Specific recommendations for Goal #4 include:

- Restore native shrubland and associated undershrub grass/forb species to promote alternative winter forage.
- Restore native grassland species and natural hydrology across alluvial fans in the north and eastern portion of the refuge.
- Consider removing livestock grazing and haying from creek corridors for some extended period of time, especially along Deadman Creek, to restore riparian habitats.
- Rotate livestock among smaller grazing units during different times of the year.
- Consider alternative management strategies to reduce or redistribute elk on the refuge.
- Prevent the reintroduction of native ungulate species that may impact current or restored vegetation communities until existing over-browsed conditions have been controlled and herbivory and grazing is better understood in relation to existing plant species and restoration efforts.

Future management of Baca NWR should include regular monitoring and directed studies to determine how ecosystem structure and function are changing, regardless of whether restoration and management options identified in this report are undertaken. Management activities on Baca

NWR should be done in an adaptive management framework where: 1) predictions about community response and water issues are made relative to specific management actions and 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action. Especially important categories of information and monitoring needs for Baca NWR include:

1. Surface and groundwater quantity and quality
2. Restoring natural water flow patterns and water regimes
3. Long-term changes in vegetation and animal communities

Cary Aloia

Cary Aloia

INTRODUCTION

Baca National Wildlife Refuge (NWR) currently contains 85,942 acres in the eastern portion of the San Luis Valley (SLV) in south-central Colorado (Fig. 1). Acquisition of land for the refuge, with an approved 92,500 acre boundary, was authorized by Congress in 2000 as part of the Great Sand Dunes National Park and Preserve Act of 2000 (USFWS 2005). This legislation, in combination with previous land acquisitions by the Great Sand Dunes National Park, U.S. Forest Service, The Nature Conservancy (TNC), Colorado State Land Board, Colorado Parks and Wildlife Department (CPW), and U.S. Bureau of Land Management (BLM) sought to protect over 500,000 contiguous acres in the eastern SLV (Fig. 1) with an over-arching goal of protecting the hydrology, ecology, wildlife, and cultural resources of the region. Prior to establishment of Baca NWR, lands now in the refuge were previously held by TNC and the U.S. Department of the Interior and then were sold to the U.S. Fish and Wildlife Service (USFWS) over a period of time (USFWS 2005). A specifically defined wildlife conservation mission for Baca NWR was not immediately established at acquisition, however, a "Conceptual Management Plan" developed for Baca NWR in 2005 adopted the national mission of the USFWS NWR System "to administer a national network of lands and waters for the conservation, management and, where appropriate, restoration of the fish, wildlife, and plant resources and their habitats" (USFWS 2005). The purpose of the Baca NWR was amended in 2009 "to restore, enhance, and maintain wetland, upland, riparian and other habitats for wildlife, plants and fish species that are native to the San Luis Valley" (Omnibus

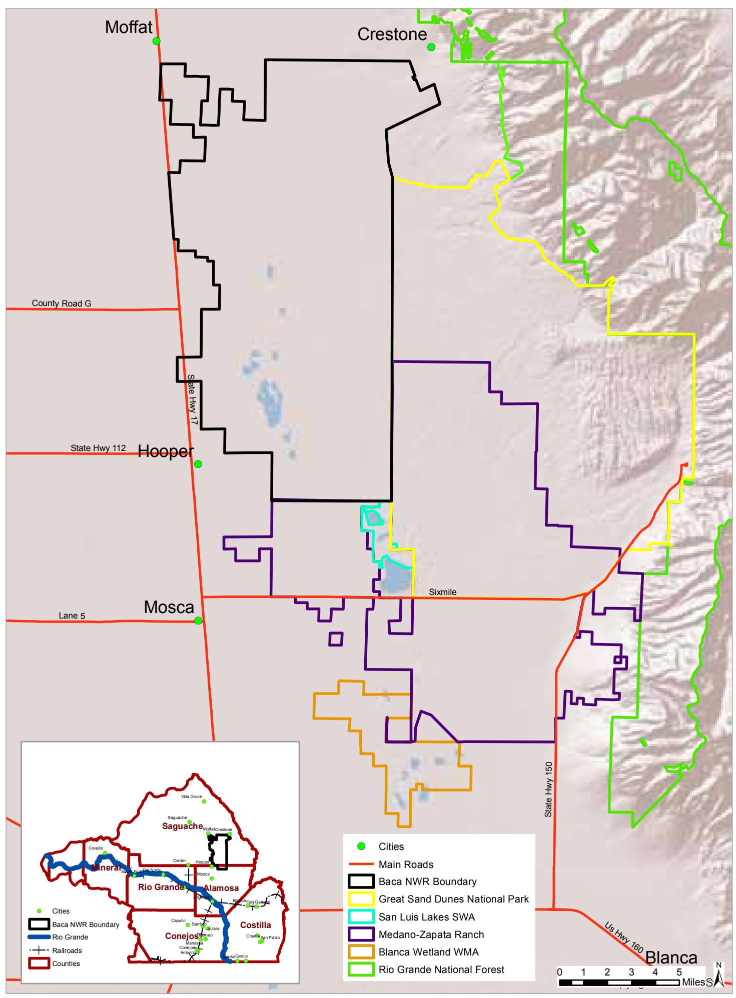

Figure 1. General location of Baca National Wildlife Refuge and proximity to other nearby public lands in the San Luis Valley, Colorado.

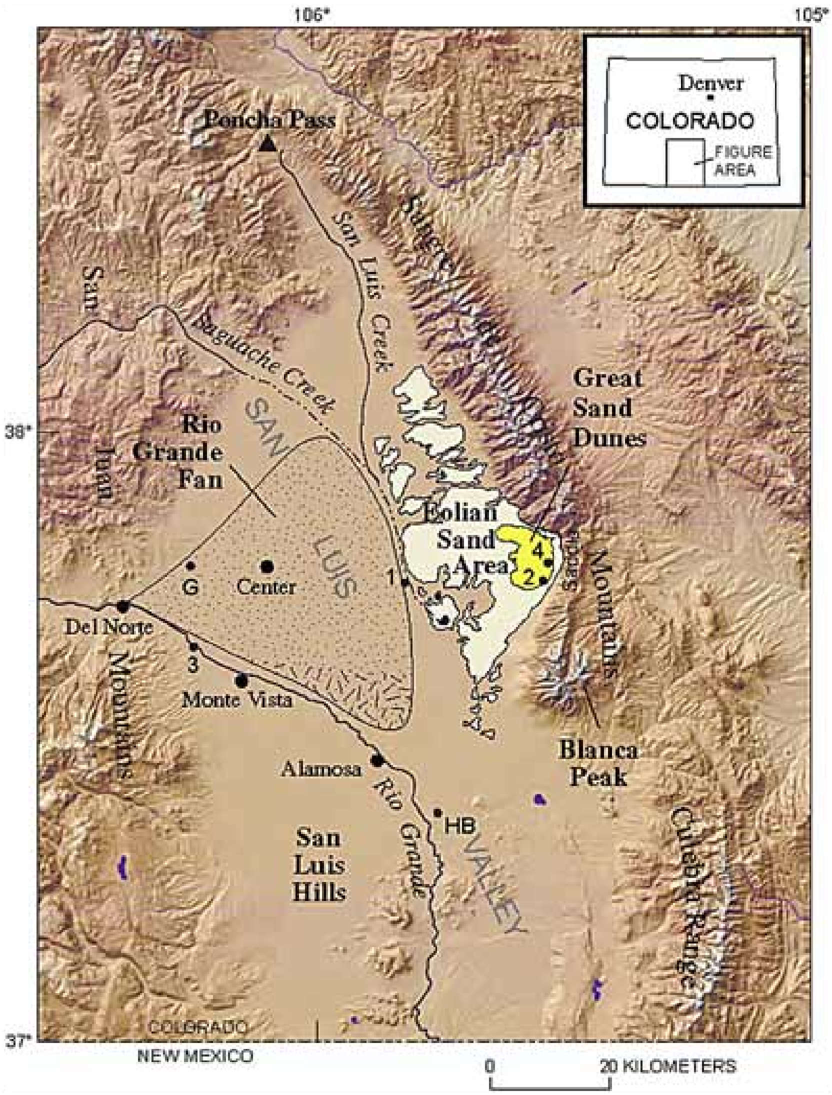

Figure 2. Location of the Eolian sand area and Rio Grande Fan in the San Luis Valley (from Madole et al. 2008).

Appropriations Act, 2009, H.R. 1105). This Act also specified certain requirements including that Baca NWR “be administered to the maximum extent practicable to (A) emphasize migratory bird conservation; and (B) take into consideration the role of the Refuge in broader landscape conservation efforts.” Finally it added the following under a new section: “(3) subject to any agreement in existence as of the date of enactment of this paragraph, and to the extent consistent with the purposes of the Refuge, use decreed water rights on the Refuge in approximately the same manner that the water rights have been used historically.”

Baca NWR is located at the base of the Sangre de Cristo Mountain foothills in the “Closed Basin” of the SLV. The Closed Basin is so named because historically little if any surface or groundwater from this area flowed out of the basin into the Rio Grande to the south. Baca NWR contains a large portion of the regionally unique eolian sand sheet (Fig. 2), including portions of alluvial fans and ephemeral creeks (North Crestone, South Crestone, Willow, Spanish, Cottonwood, Deadman, and Sand) that originate in the Sangre de Cristo Mountains and discharge into San Luis Creek (Fig. 3). These creeks historically may or may not have reached the Baca NWR annually depending on weather conditions, and more recently depending on regional drought and groundwater pumping. Part of Baca NWR lies within the area referred to as the “Upper Sump” area of the Closed Basin. The southern part of the Upper Sump that includes part of Baca NWR is shown in Figure 4 and it historically received water from the above creeks during high flow events and also from Saguache and La Garita Creeks that originated in the San Juan Mountains to the west. As the name implies, the Upper Sump area is a lower elevation deflation area defined by eolian sand deposits that are thickest and most extensive on the east side of the area (Madole et al. 2008). The diverse landscape at Baca NWR historically supported heterogeneous upland salt desert shrub, grassland, creek channel, riparian woodland, wet meadow, and “playa” wetland communities (Figs. 5, 6).

Many land and water use changes have occurred in the SLV and at Baca NWR during the last century. The history of agricultural development and water use and diversion in the SLV is a classic part of western U.S. history complete with past and present conflicts over natural resources (Buchanan 1970, Emery et al. 1973, Ellis et al. 1993, Emery 1996). Many Lands now contained within Baca NWR formerly were part of the Luis

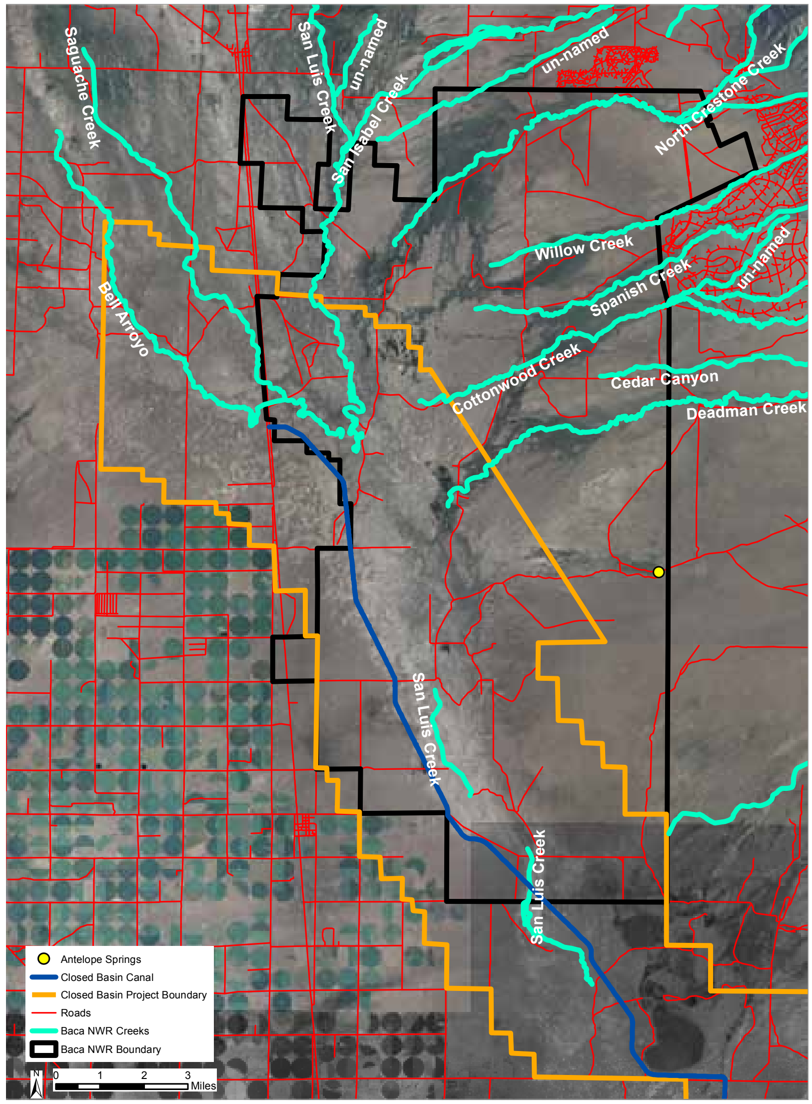

Figure 3. Creeks and closed basin features of Baca National Wildlife Refuge.

Maria Baca No. 4 Land Grant of 1860 (Fig. 5), which was granted by the United States government to the heirs of Baca after the Mexican American War. The original 1821 grant from the then newly established Mexican government to Luis Maria Baca was centered near the present day Las Vegas, New Mexico. The integrity of this original grant was lost during the Mexican-American War, but the U.S. Congress agreed to honor the rights of the original grantees and issued in its stead five, 100,000 acre "replacement grants" to the Baca family. This property changed ownership many times from 1860 to the acquisition of the area by the U.S. government. Most of the water-control and road infrastructure present on Baca NWR today was initially constructed by Alfred Collins by the 1950s for his beef cattle ranch. Water-control structures, ditches, and levees were used to divert water from the many creeks for the production of pasture and hay.

During the 1960s, the Colorado state engineer began enforcing Rio Grande Compact (hereafter "Compact") deliveries (Rio Grande Compact Commission 1939). As a result of Compact requirements, a "Closed Basin Project" through the U.S. Bureau of Reclamation (BOR) was initiated to extract, store, and subsequently divert groundwater located in the Closed Basin portion of the SLV that was not pumped for agriculture (known as "salvage water") to supplement flows in the Rio Grande (http://www.rgwcd.org). A major part of the Closed Basin Project included drilling wells and constructing a 42-mile long conveyance canal (known as the Closed Basin Canal (CBC) to move water south to the Rio Grande. Construction of the CBC started in the 1970s with continued construction on what are now Baca NWR lands in the early-1980s. The CBC starts just west of the Baca NWR, continues south, roughly paralleling the western boundary of the refuge (Fig. 7). Groundwater monitoring wells were established prior to the initiation of the Closed Basin Project and many of these wells are located on Baca NWR. A total of 82 observation wells and 170 "salvage" wells that supply water to the CBC were drilled to various depths, of which about 88 salvage wells are located on Baca NWR.

The Closed Basin Project was initially estimated to be capable of producing and delivering an estimated 100,000 acre-feet of water to the Rio Grande annually; however, actual annual volumes have been significantly less due to lower than expected water yields from the wells. Currently, the Project delivers about 15,000 acre-feet annually. High total dissolved solids and iron bacteria infestations of wells also have compromised the effectiveness of this project. Regional pumping of ground-

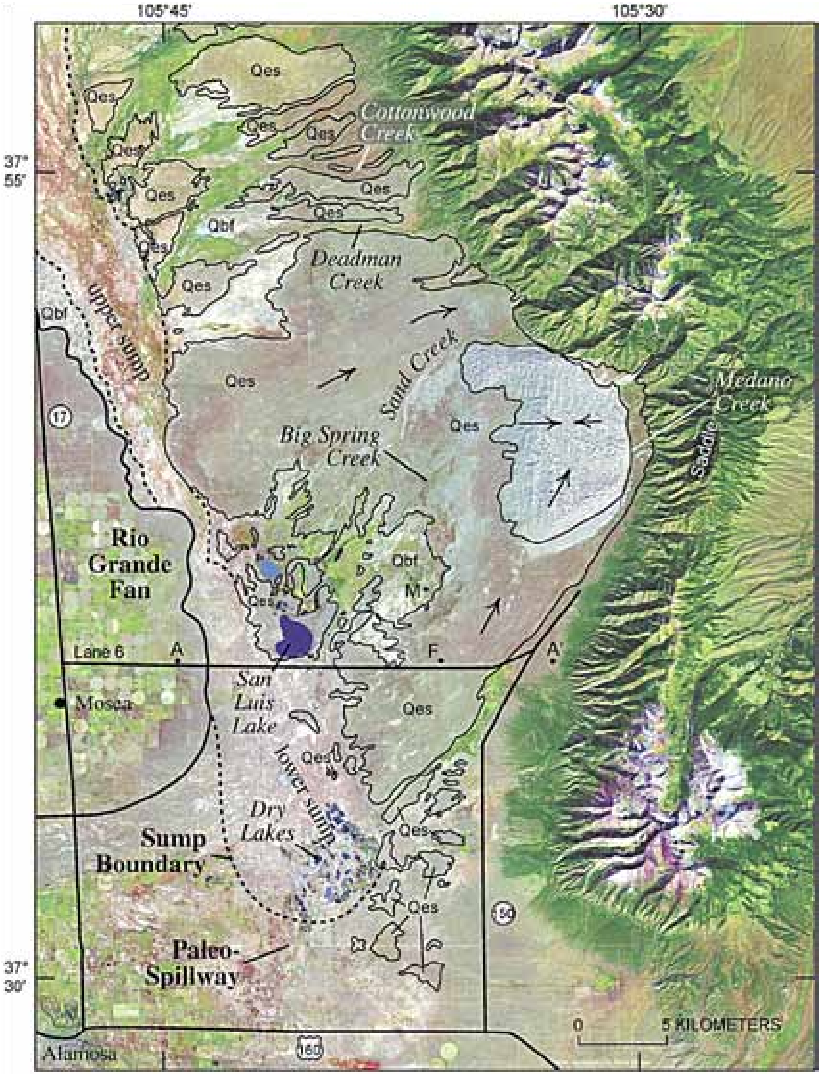

Figure 4. Location of the Upper and Lower Sump areas on or near Baca National Wildlife Refuge and the geographical proximity to the Rio Grande Fan in the San Luis Valley (from Madole et al. 2008).

water for use in center-pivot agricultural irrigation sprinklers coupled with salvage pumping from Closed Basin Project wells now exceeds recharge of the unconfined aquifer and negatively affects the hydrologic characteristics of the Baca NWR. Rules and regulations for groundwater use in Division 3, which includes the Baca NWR, currently are being promulgated by the State Engineer. Upon promulgation, Baca NWR will be required to augment for any groundwater depletions resulting from use of wells by the USFWS which may be accomplished through an augmentation plan or a contract with a groundwater sub-district (Striffler 2013).

Acquisition of most of the private lands for Baca NWR did not include mineral rights. Lexam Explorations, Inc., which owns 75% of the mineral rights below the surface of the refuge (Striffler 2013), has proposed drilling two experimental wells to explore for oil and gas. An Environmental Assessment (EA) was conducted and completed in 2011 resulting in a "Finding of No Significant Impact" for drilling of the exploration wells. As part of the EA the USFWS established terms and conditions in order to help protect the natural and cultural resources of the refuge should drilling occur. These wells have not been drilled but may occur in the future under their Plan of Operations (Striffler 2013). An improved road established along an old wagon road running north-south bisects the northern portion of the refuge east to west to allow for transportation to and from the well pads. Access to new drilling sites would require upgrading existing 2-track roads and creating a new road.

In 2011 the USFWS initiated a Comprehensive Conservation Plan (CCP) for the San Luis Valley NWR Complex including Baca NWR. Congress mandated that the USFWS would prepare CCPs for each NWR in the 1997 National Wildlife Refuge Improvement Act. CCPs seek to identify the role of each NWR in supporting the mission of the NWR System and provide guidance for refuge management for a 15-year period from the CCP completion date. CCPs articulate management goals and specific objectives and strategies to achieve these goals. As part of the CCP effort, the USFWS recognized the need for more holistic system-based approaches to evaluate future restoration and management efforts. Recently, Hydrogeomorphic Methodology (HGM) has been used to evaluate ecosystem restoration and management options on many NWR's in USFWS Region 6, which can help facilitate the CCP process (e.g., Heitmeyer and Fredrickson 2005; Heitmeyer et al. 2009; Heitmeyer et al. 2010a,b; Heitmeyer et al. 2012; Heitmeyer and Aloia 2013a,b). HGM consists of collating and interpreting historical

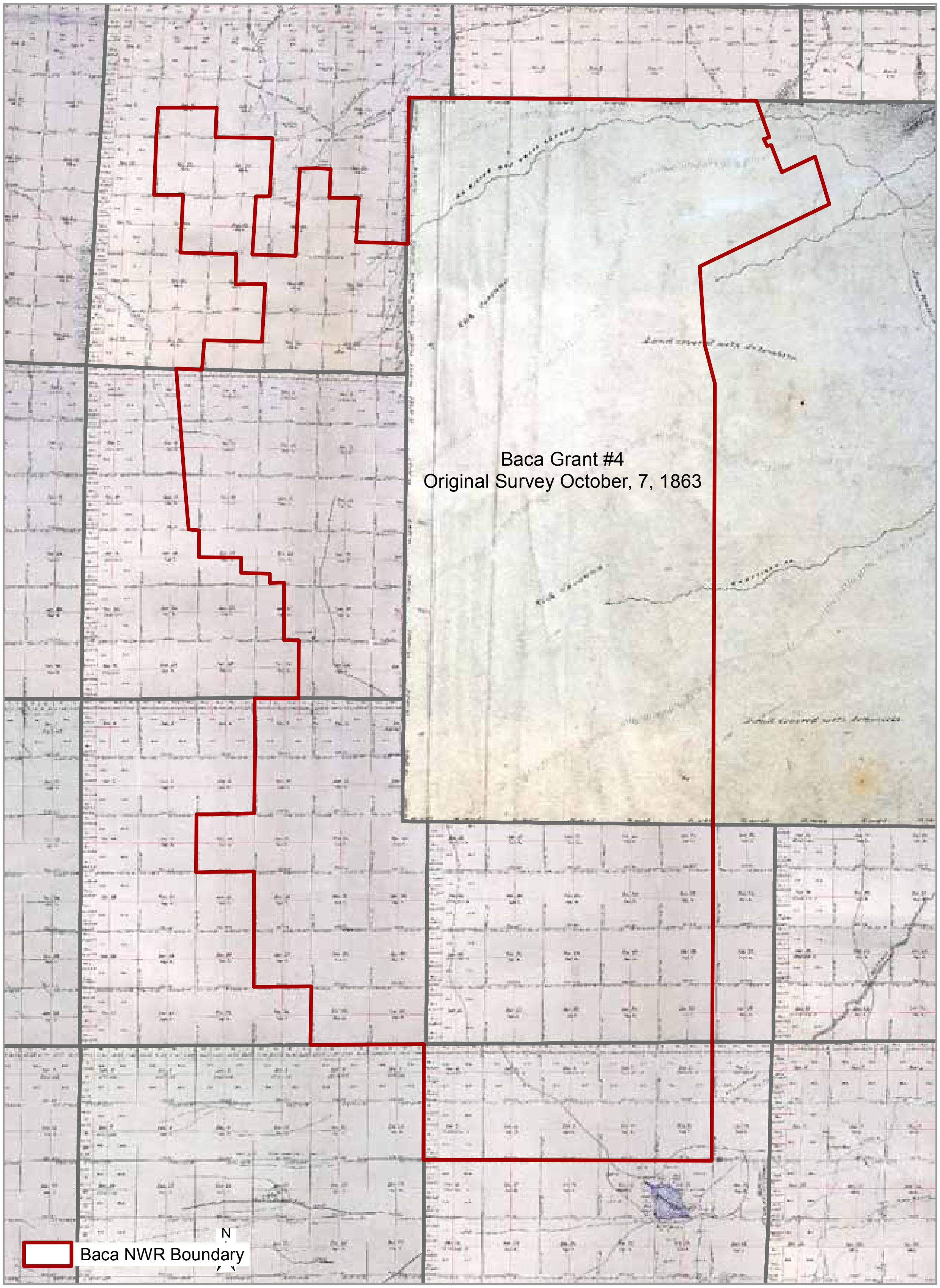

Figure 5. Historic location of creeks, lakes and roads on Baca National Wildlife Refuge (adapted from late 1800s GLO survey).

Figure 6. 1941 aerial photo of Baca National Wildlife Refuge.

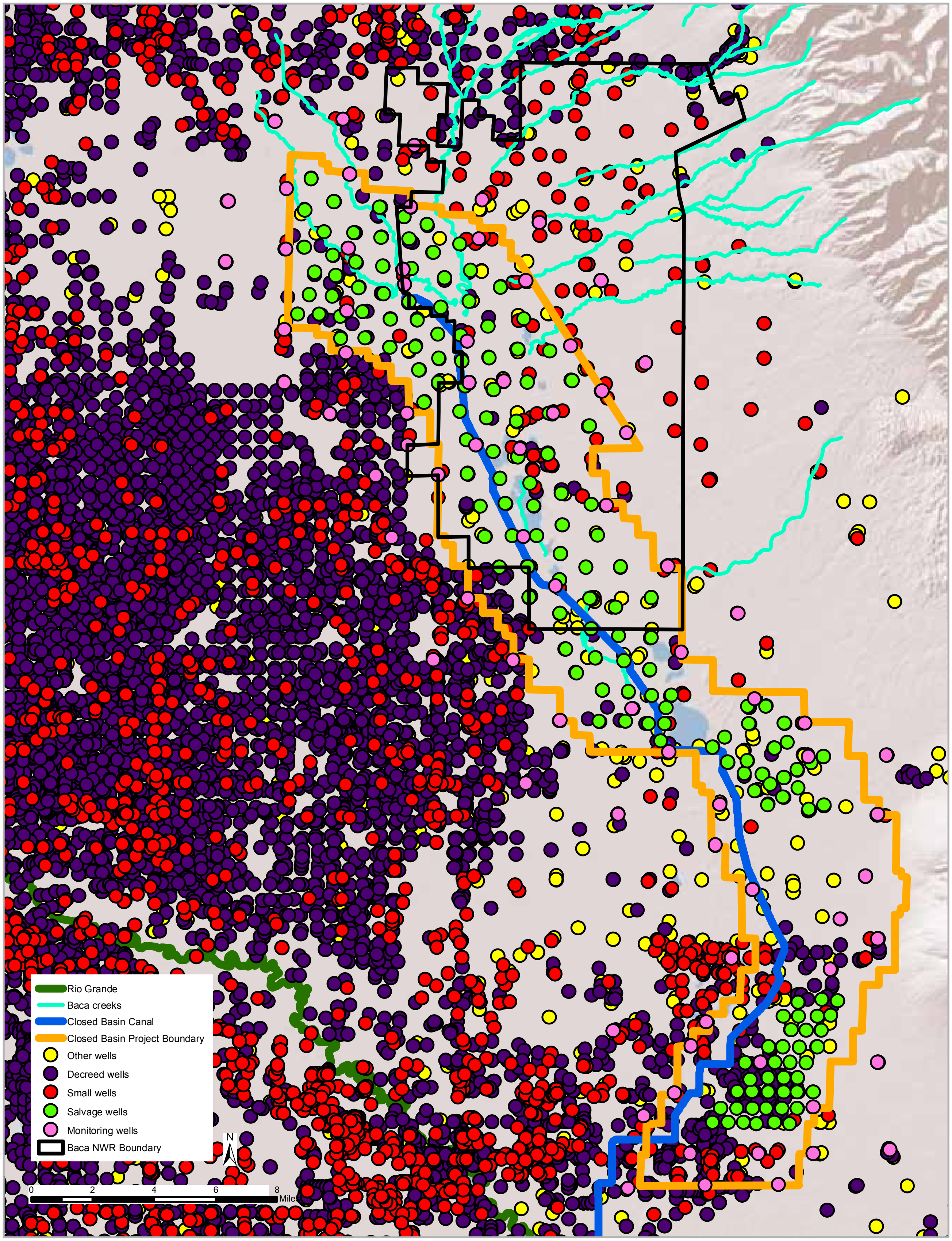

Figure 7. Wells, canals, and creeks in the Baca National Wildlife Refuge region.

and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) aerial photographs and maps, 6) land cover and plant/animal communities, and 7) physical anthropogenic features of ecosystems (Heitmeyer 2007, Klimas et al. 2009, Theiling et al. 2012, Heitmeyer et al. 2013). This information provides a context to understand the physical and biological formation, features, and ecological processes of lands within a NWR and surrounding region. The historical assessment provides a foundation, or baseline condition, to determine what changes have occurred in the abiotic and biotic attributes of the ecosystem and how these changes have affected ecosystem structure and function. Ultimately, this information helps define the capability of the area to provide key ecosystem functions and values and identifies options that can help to restore and sustain fundamental ecological processes and resources.

This report provides HGM evaluation of Baca NWR with the following objectives:

1. Describe the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Baca NWR region.

2. Document changes in the Baca NWR ecosystem from the Presettlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.

3. Identify restoration and management options incorporating ecological attributes needed to restore specific habitats and conditions within various locations on the Baca NWR region.

THE HISTORICAL BACA ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

The SLV is the largest of a series of high-altitude intermountain basins located in the Southern Rocky Mountains (Jodry and Stanford 1996) and is part of the much larger Rio Grande Rift Zone that extends from southern New Mexico north through the SLV to its northern terminus near Leadville, Colorado (Chapin 1971, Bachman and Mehnart 1978). The SLV is a compound graben depression, bordered on the north and east by the Sangre de Cristo Mountains, which resulted from extensive block faulting during the Laramide Orogeny. The Sangre de Cristo Mountains are bounded on the east and west sides by normal faults. These fault lines in the SLV extend north of the Great Sand Dunes along the base of alluvial fans of the Sangre de Cristo Mountains. The San Juan Mountains bound the SLV on the west and were created by extensive Tertiary volcanism about 22 to 28 million years before the present (BP) (McCalpin 1996). The Oligocene volcanic rocks of the San Juan Mountains slope gradually down to the SLV floor where they are interbedded with alluvial-fill deposits (BLM 1991). This volcanic rock layer originating from the San Juan Mountains extends over the Alamosa Horst, a buried ridge of the normal fault, separating the SLV into the Monte Vista Graben to the west and the Baca Graben to the east. Baca NWR lies within the northeast portion of the Closed Basin of the Baca Graben (Fig. 8). The Closed Basin depression may be a result of subsidence and wind deflation which, over time, has been a factor in preventing external surface drainage to the Rio Grande.

From the Pliocene to middle Pleistocene time, a large high altitude lake, Lake Alamosa, occupied most of the SLV (Machette et al. 2007; Figs. 9, 10). This ancient lake went through several cycles of drying and flooding, ultimately accumulating

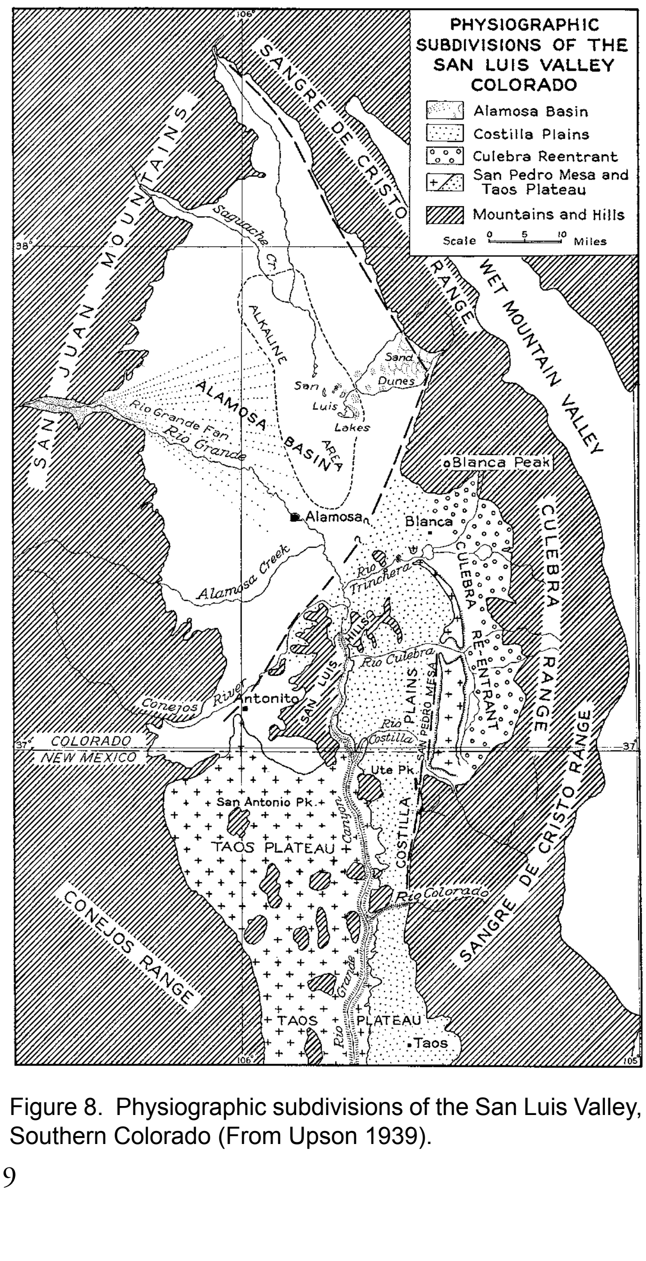

Figure 8. Physiographic subdivisions of the San Luis Valley, Southern Colorado (From Upson 1939).

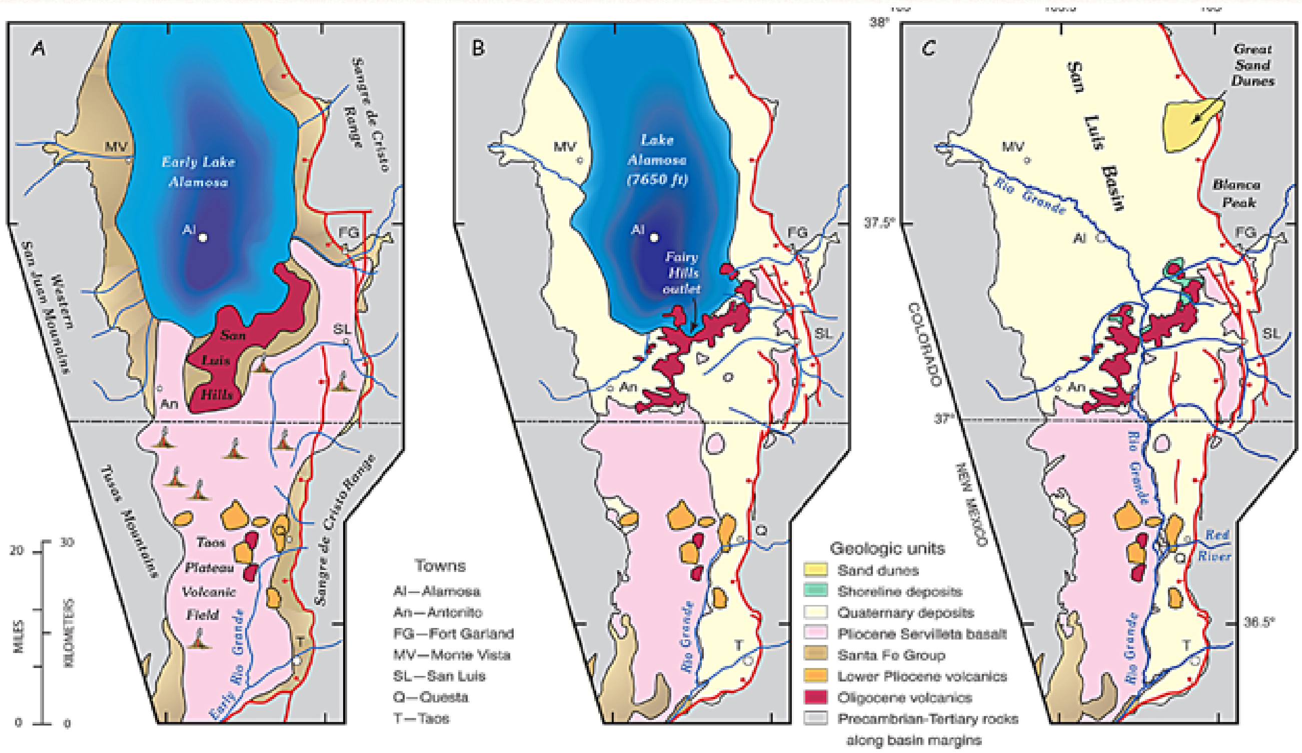

Figure 9. Simplified geological map of the San Luis Basin showing generalized geology and drainage patterns for the time intervals: a) 3.5-5 million years before the present (BP), b) 440,000 years BP, and c) current (From Machette et al. 2007).

sediments that are designated as the Alamosa Formation consisting of alternating beds of gravel and either sand, sandy silt, or sandy clay (Siebenthal 1910; Madole et al. 2008). Lake Alamosa existed for about three million years when it overtopped a low wall of Oligocene volcanic rocks of the San Luis Hills and carved a deep gorge that flowed south into the Rio Grande, entering at what is now the mouth of the Red River (Madole et al. 2008). Thus, interbedded clay layers in the Alamosa Formation are freshwater lake clays of varying color and depth and are more extensive in the northern portion of the Alamosa Basin where deposits may be up to 19,000 feet thick. The Alamosa Formation that contains Quaternary-age younger alluvium and surficial deposits is underlain by the Santa Fe Group Formation rocks (Figs. 11, 12). The Santa Fe group is comprised of Pliocene and Miocene formations underlain by Echo Park alluvium and then Precambrian rocks.

After the retreat of Lake Alamosa, and during the Pleistocene, sediments were deposited differentially during and between glaciations as melt water flowed through the Rio Grande system as far east as San Luis Creek. Wind moved eolian sediments from an area just east of the historic Rio Grande fan in a northeasterly direction towards the Great Sand Dunes in drought periods (Fig. 2). Wind deflation occurred during periods of drought between periods of intermittent flooding. Eolian surfaces such as the sabkha, or salt-encrusted plain, were deflated and transitioned from a sand sheet to a dune field, and eventually to sand ramps on what is now the Great Sand Dunes National Park. This Eolian sand covers an area of about 625 km2, of which 553 km2 consists of low relief dunes and sheet sand (Fig. 2; Madole et al. 2008); some of which occurs on the Baca NWR. As much as 70% of the particles comprising the Great Sand Dunes are of San Juan Mountain or volcanic origin with the remaining particles originating from the Sangre de Cristo Mountains. The erosion of these particles occurred in what has been described as the Upper and Lower Sump areas, where a heterogeneous playa and dry lake wetland complex occurs along the axis of the Closed Basin in the western portion of Baca NWR (Figs. 2,4; Madole et al. 2008).

The Rio Grande enters the SLV near Del Norte, Colorado and flows to the south and east along the southern boundary of the Rio Grande alluvial fan (Fig. 2). The river takes a more southerly direction at the town of Alamosa, Colorado where a low topographic and hydrologic divide (Powell 1958) historically stretched from the northern edge of the Rio Grande Alluvial fan to eight miles east of Alamosa and north to Blanca, which separated the Rio Grande floodplain from the Closed Basin to the north (Leonard and Watts 1989). Some current information indicates that the hydrologic divide that historically prevented hydrologic connectivity between the Rio Grande and areas to the north no longer exists due to ground water extraction; the divide may be reformed should the aquifer be restored to sustainable levels (Davis Engineering 2007). The surficial geomorphology of the area in and around Baca NWR has been influenced by the many creeks that eventually flow into the Sump areas of the Closed Basin. Sediments carried by Saguache and La Garita creeks that originate in the San Juan Mountains, are different than those in creeks that originate in the Sangre de Cristo Mountains. The piedmont creeks that originate in the Sangre de Cristo Mountains historically carried large volumes of sediment during the relatively short, but high discharge, peak flows in late spring, which created many sediment deposition and scour areas across Baca NWR (Madole et al. 2008).

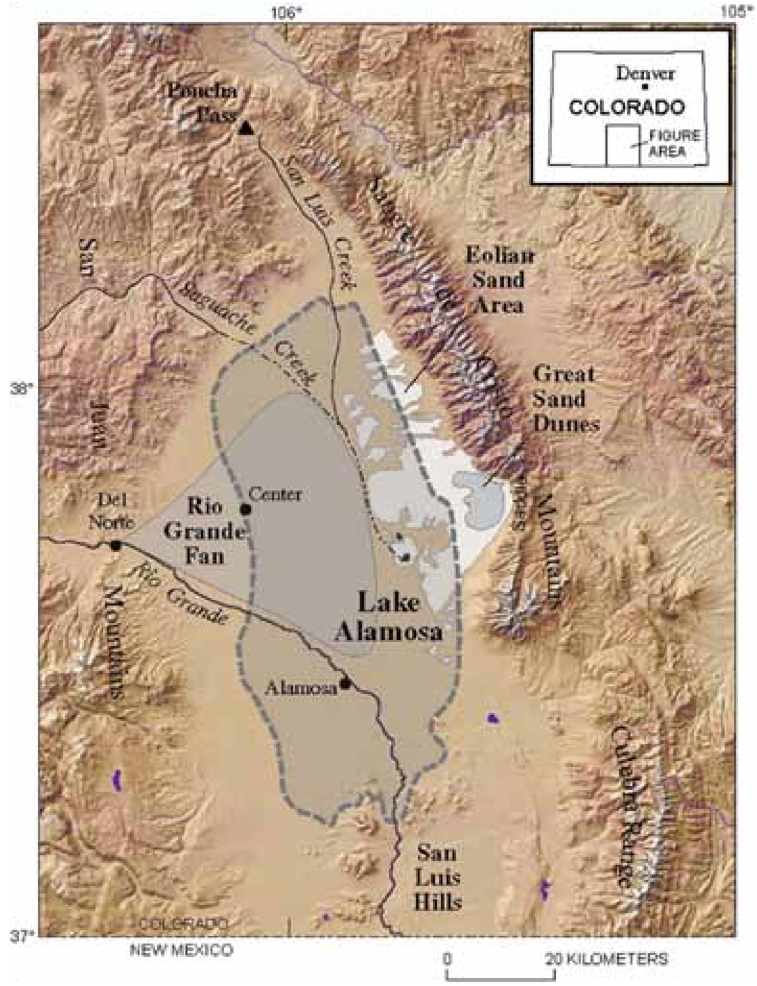

Figure 10. Location of Lake Alamosa in relation to the eolian sand sheet and Rio Grande fan in the San Luis Valley (From Madole et al. 2008).

SOILS

About 37 distinct soil types are present on Baca NWR (Fig. 13). Generally, soil distribution across Baca NWR reflects: 1) historical movement, deposition, and scouring of sediments carried to the refuge area by ephemeral creeks that originate in the Sangre de Cristo Mountains; 2) avulsion movements of San Luis Creek; and wind deflation (Soil Conservation Service (SCS) 1981). Wind deflation of basin sediments has brought the groundwater in closer proximity to the ground surface through removal of particles over time. Through soil capillarity, soil salts are brought to the surface that alters the chemical nature of surface water and subsequent sediments that are transported by wind. Wind deflation of the sabkha and eolian sand sheet has created temporary or playa lakes throughout the western and southern portions of the refuge (seen in the partial 1941 aerial photo, Fig. 6) and in the dune fields. Many types of dunes have been created as a result of the wind deflation of the sump area (Madole et al. 2008).

Baca NWR contains three dominant soil-land associations: 1) the Space City-Cotopaxi (SCC) in the eastern and southern portion, 2) the Big Blue-Gerrard (BBG) within the floodplain of San Luis Creek and most of Cottonwood Creek, and 3) the Hooper-Hagna-Hapney (HHH) that is located adjacent to the BBG to the west and east (SCS 1981). The SCC soil-land association typically is characterized by deep soils that are level to moderately sloping in dune-like topography that is intersected by intermittent streams that are somewhat excessively drained. Soils in this association are loamy sand to sand underlain by calcareous loamy sand or sand. Dominant soil series include Space City, Cotopaxi, and Laney types. Space City soils occur on 0-15 percent slopes and cover about 22% of Baca NWR. Cotopaxi sand is on 2-15 percent slopes on dune-like hills and covers 11.5% of the refuge. Laney loam is on 0-3 percent slopes on floodplains and fans, formed in calcareous alluvium with saline-alkali characteristics, and covers about 12% of the refuge. Historical vegetation typical of SCC soils includes grasses and shrubs (SCS 1981).

The HHH association on Baca NWR includes deep soils, with saline and alkali characteristics, on nearly level surfaces of floodplains and terraces. The two major soils of this association, Hooper and Hapney clay loam, each cover about 7% of Baca NWR (Fig. 13). The water table in these areas generally is high during the spring and summer and historically supported salt desert shrub and salt tolerant grassland communities; some of these areas are in relict lake basins (SCS 1981). Laney loam, mentioned above, also can occur within the HHH areas. The BBG association is commonly mapped to floodplains along streams on Baca NWR and consists of clay loam or loamy surfaces underlain by clay loam and gravelly sandy clay loam. These soils have seasonally high water tables and may be flooded for short periods (SCS 1981). This soil association occurs within the Upper Sump area where most playa lakes occur and ephemeral creeks empty onto the San Luis Creek floodplain.

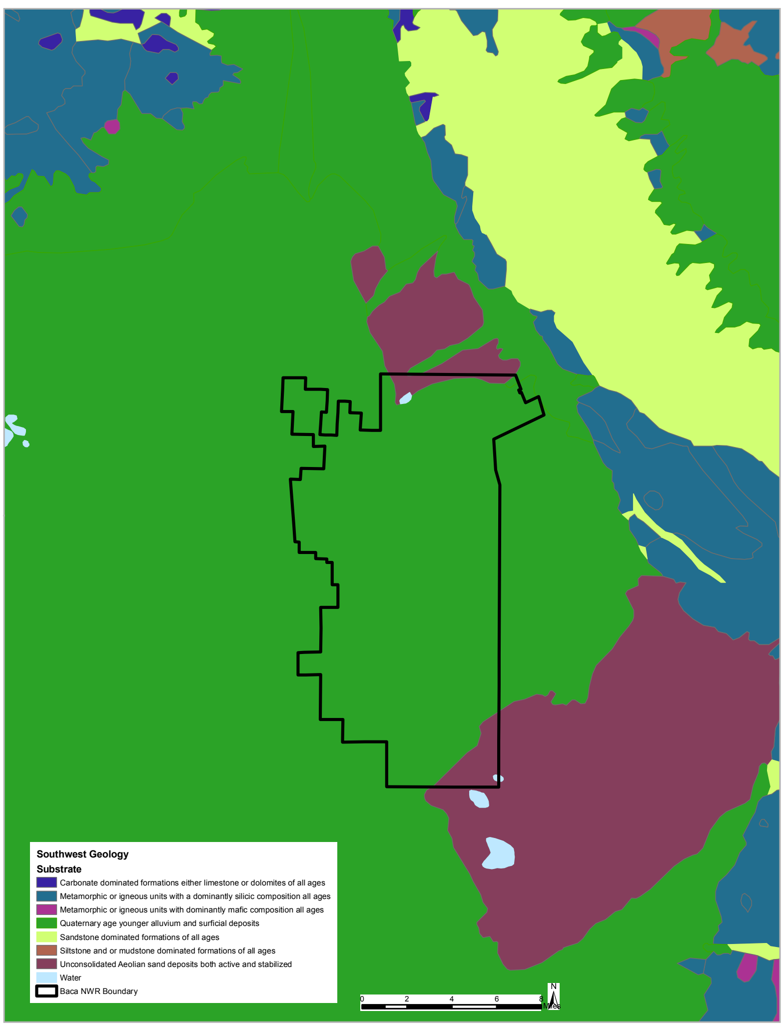

Figure 11. Geological surfaces of Baca National Wildlife Refuge (information obtained from USDA Data Gateway website).

TOPOGRAPHY

The SLV is a large high elevation basin lying in elevation at > 7,500 feet above mean sea level (amsl). Light detection and ranging (LiDAR) elevation surveys have been completed for the Baca NWR region and elevations on and immediately adjacent to the refuge range from 7,525 to 7,875 feet amsl (Fig. 14). The historic floodplain of San Luis Creek and the ephemeral creeks draining the Sangre de Cristo Mountains contain relict scour and deposition surfaces related to historic fluvial dynamics. The surficial topography of the Baca NWR region contains geomorphic features such as natural levees, scroll bars, abandoned creek channels, alluvial fans, and sand sheets and dunes. A majority of wetlands within the San Luis Creek floodplain are at an elevation ranging from 7,527 and 7,532 feet amsl with adjacent dunes and ridges at about 7,537 feet amsl.

CLIMATE AND HYDROLOGY

The climate of the SLV is semi-arid, with cold winters and moderate

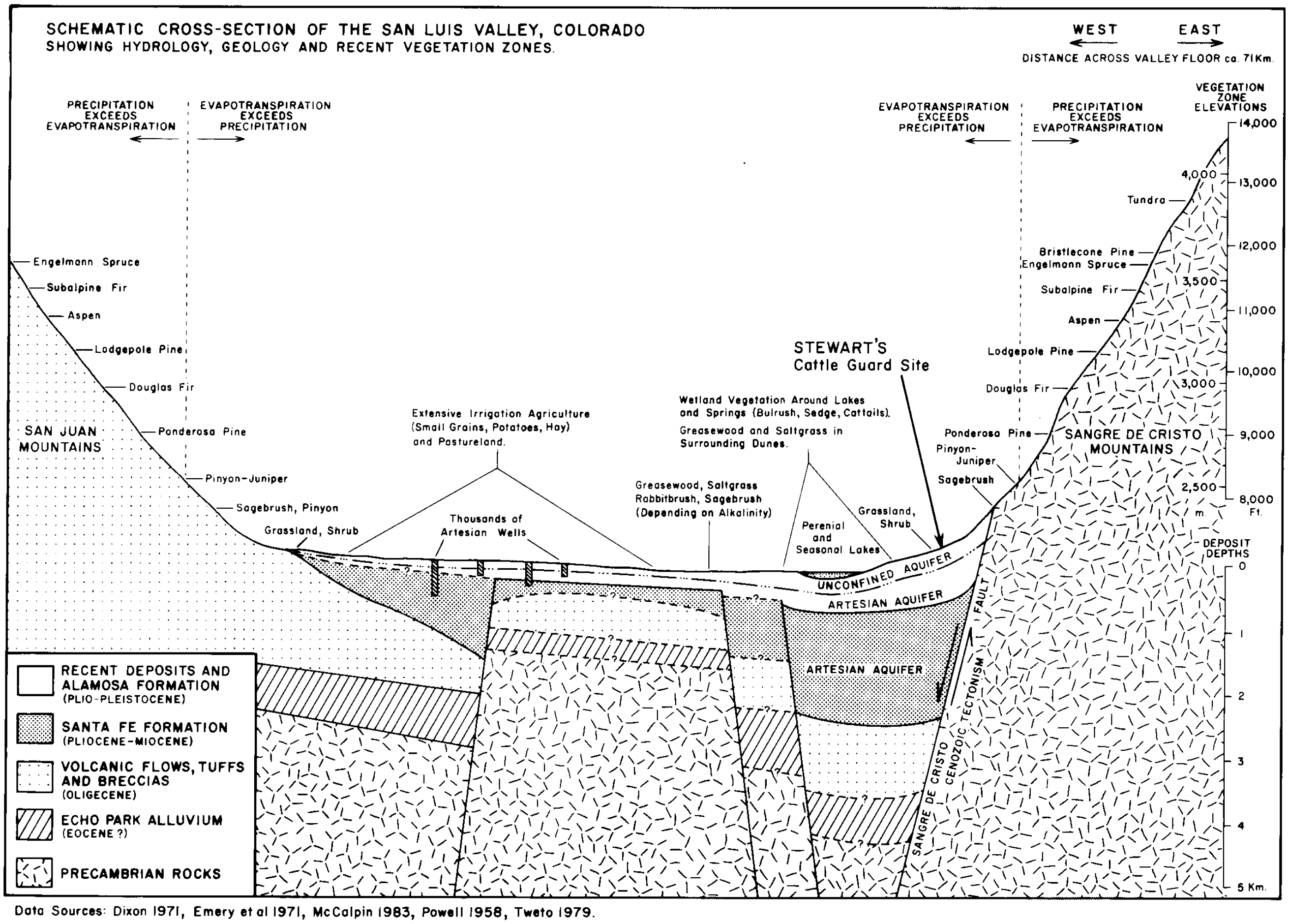

Figure 12. Schematic cross-section of the San Luis Valley, Colorado showing hydrology, geology, and recent vegetation zones (from Jodry and Stanford 1989).

summers (Table 1). The Baca NWR region lies adjacent to the Sangre de Cristo Mountains but is still influenced by the rain shadow of the San Juan Mountains. Typically the SLV receives an average of seven inches of precipitation per year (Table 2); however, the Great Sand Dunes National Park on the southeast side of Baca NWR receives an average of about 11 inches/year. About 60% of this precipitation occurs as rain in July and August. The source of this summer moisture is the Gulf of Mexico and Gulf of California derived from monsoonal flow from the desert southwest. Snow cover usually is sparse in the SLV and sometimes is completely lacking during much of the winter (BLM 1991). Wide seasonal and annual variation in precipitation can occur in the SLV. Long-term precipitation data from Saguache, CO suggest that alternating low and high precipitation patterns occur at about 30-year intervals (Fig. 15, Striffler 2013). Dry periods in the long-term precipitation pattern occurred in the 1890s, 1930s, early-1950s, early-1970s, late-1980s, and the mid-2000s (Thomas 1963; Grissino-Mayer et al. 1998). Long-term trends in annual precipitation vary somewhat based on location throughout the SLV. The long-term annual precipitation trend for Saguache, Colorado is generally stable while trends at Crestone, Colorado indicate a gradual decline in precipitation (Striffler 2013). Recent studies have analyzed tree-ring data to reconstruct streamflow throughout the Rio Grande Basin (Correa 2007). These data suggest that the periodicity and duration of individual droughts has increased over the last 730 years.

Mean annual temperature for the SLV is 43^{o} Fahrenheit (F) although temperatures of -20 to -30^{o} F are expected each year in the winter with highs in the summer in the 80’s. The annual frost-free growing season for the SLV averages about 90 days and occurs from late May through early September (Emery 1996) with July and August typically being the only consistent completely

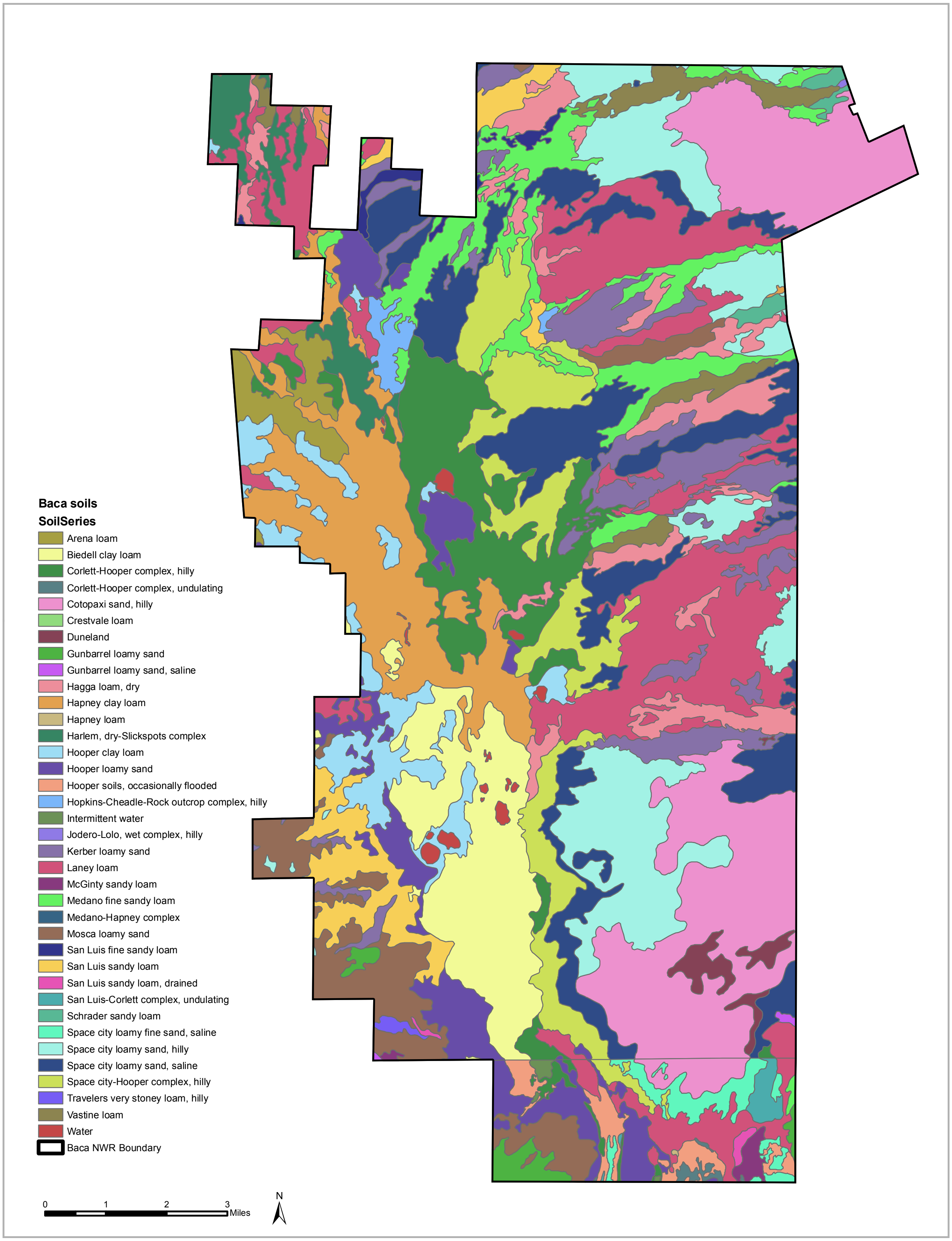

Figure 13. Soil series of Baca National Wildlife Refuge (SSURGO data).

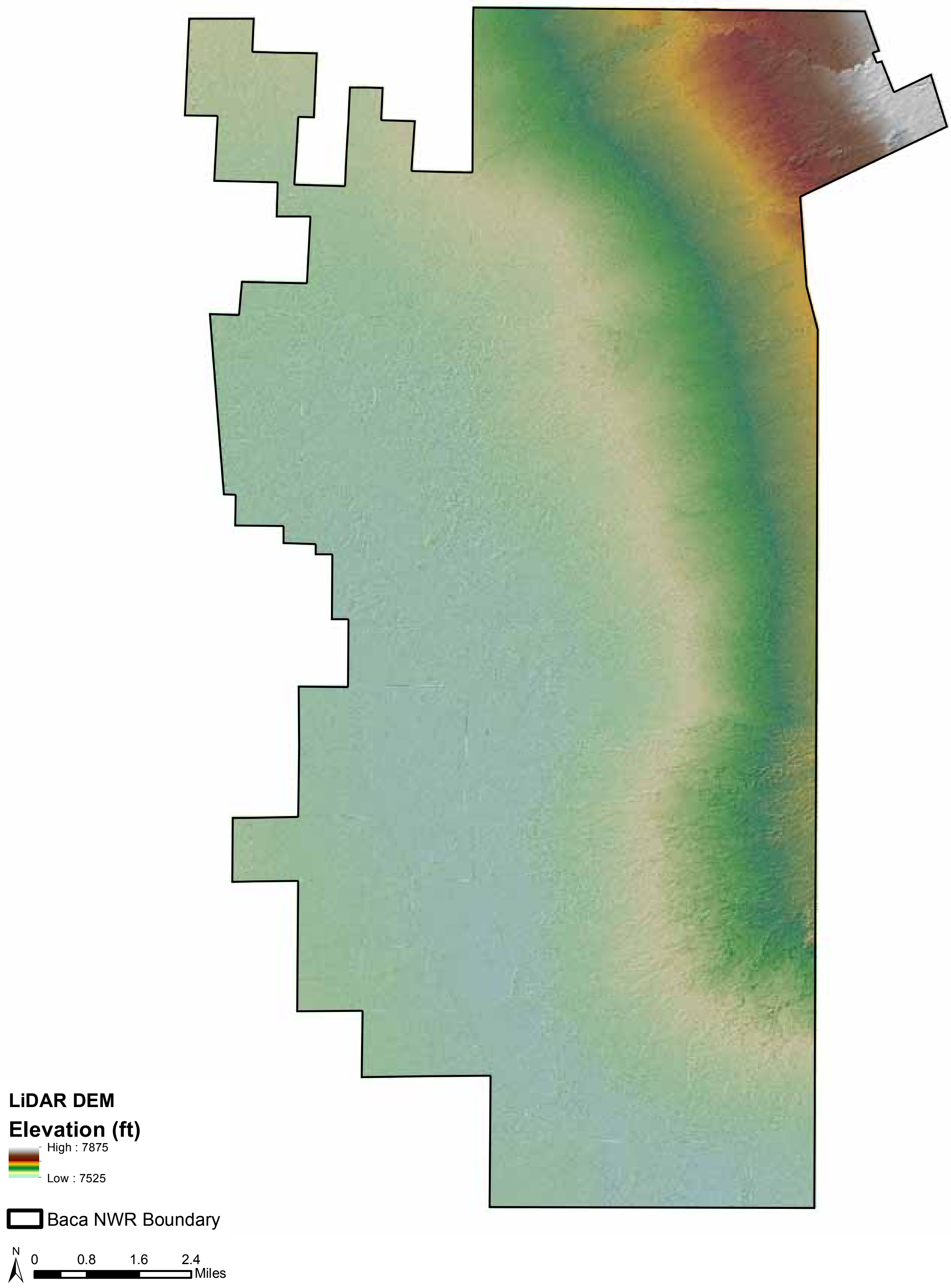

Figure 14. Elevation (resolution of 1m) derived from LiDAR surveys for Baca National Wildlife Refuge.

Table 1. Temperature data from 1971-2000 at Great Sand Dunes, CO (from National Climatic Data Center, www.ncdc.noaa.gov).

Temperature (˚F)																					
Mean (1)				Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	34.3	8.0	21.2	67	1971	31	29.2	1986	-25	1963	13	13.0	1984	1359	0	.0	.0	1.3	12.2	31.0	5.4
Feb	38.7	12.7	25.7	63	1986	26	36.0	1995	-22	1985	2	17.6	1979	1101	0	.0	.0	3.6	6.1	28.1	2.7
Mar	46.2	21.3	33.8	72	1971	26	40.2	1999	-7	1965	3	28.6	1973	970	0	.0	.0	13.2	1.3	29.3	.1
Apr	54.6	27.6	41.1	78	1989	22	46.4	1992	-6	1973	8	34.6	1973	717	0	.0	.0	22.7	.3	21.7	@
May	64.8	36.6	50.7	89	2000	24	57.3	1996	15+	1962	1	46.5	1995	445	1	.0	.0	29.5	.0	8.2	.0
Jun	76.1	45.6	60.9	96	1982	29	65.0	1994	25	1954	7	56.2	1983	146	21	.0	.4	29.9	.0	.5	.0
Jul	80.2	50.8	65.5	94+	1982	18	68.9	1980	31	1967	17	62.5	1995	42	59	.0	.6	31.0	.0	.0	.0
Aug	77.7	49.3	63.5	89	1954	2	66.6	2000	33+	1967	18	60.5	1974	73	27	.0	.0	31.0	.0	.0	.0
Sep	70.8	42.3	56.6	87+	1990	1	61.3	1998	22+	1985	30	53.8+	1973	256	3	.0	.0	29.7	.0	2.1	.0
Oct	59.9	32.2	46.1	80	1963	5	50.7	1979	2	1993	30	40.1	1984	587	0	.0	.0	26.7	.3	16.1	.0
Nov	45.0	19.8	32.4	67+	2001	1	39.7	1999	-12	1957	28	24.8	1972	978	0	.0	.0	11.4	4.1	28.9	.8
Dec	35.8	10.2	23.0	60	1970	9	32.8	1980	-19+	1961	13	16.1	1978	1303	0	.0	.0	1.9	10.9	30.9	4.4
Ann	57.0	29.7	43.4	96	Jun 1982	29	68.9	Jul 1980	-25	Jan 1963	13	13.0	Jan 1984	7977	111	.0	1.0	231.9	35.2	196.8	13.4

frost-free months. Evapotranspiration (ET) rates in the SLV typically are 45-50 inches per year (Leonard and Watts 1989, Ellis et al. 1993). A precipitation deficit (potential ET minus precipitation) occurs every month of the year; deficits are largest in June (Leonard and Watts 1989). Prevailing winds usually are from the south-southwest with wind speeds of 40 miles per hour common in spring and early summer.

Historically, the Closed Basin of the SLV received surface water inputs from creeks originating in the Sangre de Cristo and San Juan Mountains and from limited onsite precipitation. The mountain creeks that drain into the Closed Basin are derived from a combined watershed drainage area of about 1,800 mi2 (Leonard and Watts 1989). Water from creeks originating in the Sangre de Cristo Mountains historically emptied into San Luis Creek and terminated in the Lower Sump area south of Baca NWR (Figs. 2, 4). Saguache and La Garita creeks originated in the Cochetopa Hills and La Garita Mountain areas, respectively, of the San Juan Mountains (Figs. 2, 16). South of Saguache, CO, Saguache Creek lacks a single distinct channel and surface water historically exhibited undefined sheetflow across the land surface in large snowpack years. This water temporarily and shallowly flooded shrublands and grasslands as it flowed toward San Luis Creek on the Baca NWR (Hopper et al. 1975). La Garita Creek flowed from the west meeting with Saguache and San Luis creeks on Baca NWR. Flows from these creeks have been measured near the San Juan Mountain foothills where some creek water infiltrates to recharge SLV aquifers (Anderholm 1996); consequently the historical amount of surface water in these creeks at the confluence with San Luis Creek is unknown. Saguache, La Garita, and San Luis creeks historically were perennial drainages except during drought and low snowpack years (Anderholm 1996).

Creeks originating in the Sangre de Cristo Mountains that flowed directly onto what is now the Baca NWR include San Luis, San Isabel, North and South Crestone, Willow, Cottonwood, Deadman, and Spanish creeks. Also, some flow from Sand Creek entered the refuge at the very southern end of the refuge (Fig. 16). Seasonal flow in these creeks historically was bimodal with increased flow in spring following snowmelt and again in July and August when monsoonal rains caused flash flooding in the creeks. Many of these creeks were ephemeral because snowmelt runoff from the nearby 13,000 to 14,000-foot mountain peaks was short duration but high flow volume and velocity. Some creeks were perennial, at least in some portions of their course, such as Cottonwood

Creek. However, these creeks often did not have enough total discharge to reach San Luis Creek, in part because some creek water infiltrated and recharged local aquifers along the alluvial fan of the Sangre de Cristo Mountains. Seasonal discharge in North Crestone Creek, one of the perennial creeks on the refuge, ranged between an average of 2 and 45 cubic feet/second (cfs) for the period of record (USGS monthly streamflow statistics, 1936-1981) with peak discharge usually occurring in June (Striffler 2013, Figs. 17a,b). Certain creeks also had flows onto refuge areas in winter when temperatures were above average and snowmelt occurred.

The thick basin-fill deposits of interbedded clay, silt, gravel, and volcanic rock form aquifers in the SLV (Burroughs 1981, Wilkins 1998, Hanna and Harmon 1989). The two main aquifers, the confined and unconfined aquifers, are separated by a confining layer of discontinuous clay beds and volcanic rocks (Fig. 18, Emery et al. 1973). The unconfined alluvial aquifer underlies Baca NWR

Table 2. Precipitation data from 1971-2000 at Great Sand Dunes, CO (from National Climatic Data Center, www.ncdc.noaa.gov).

Precipitation (inches)																								
	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/ Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	.46	.29	.74	1999	22	1.55	1979	.01+	1981	4.4	1.4	.2	.0	.02	.04	.08	.14	.21	.30	.40	.55	.75	1.10	1.45
Feb	.39	.35	.70	1989	20	1.41	1989	.03	1995	4.1	1.3	.1	.0	.05	.08	.13	.19	.24	.31	.38	.47	.60	.80	1.00
Mar	.88	.69	1.30	1992	4	2.41	1992	.12	1971	5.8	3.0	.3	@	.13	.20	.33	.45	.58	.72	.88	1.08	1.34	1.78	2.20
Apr	.90	.84	1.17	1998	3	2.16	1998	.00	1974	5.8	2.9	.3	@	.02	.08	.19	.32	.46	.63	.83	1.09	1.46	2.07	2.68
May	1.13	.96	1.95	1955	18	2.97	1993	.02	1975	7.6	3.7	.3	@	.10	.18	.33	.49	.66	.85	1.08	1.37	1.77	2.43	3.08
Jun	.88	.81	1.14	1995	30	2.41	1995	.05	1980	6.0	2.6	.3	.1	.07	.13	.24	.36	.50	.65	.83	1.07	1.39	1.93	2.46
Jul	1.69	1.40	1.83	1968	27	3.91	1998	.22	1994	10.2	4.5	.7	.2	.30	.45	.70	.93	1.17	1.42	1.71	2.06	2.52	3.27	3.99
Aug	1.95	1.89	1.45	1954	6	5.14	1993	.25	1985	11.3	5.7	.8	.2	.48	.66	.94	1.20	1.45	1.71	2.00	2.35	2.81	3.54	4.22
Sep	1.23	.96	2.10	1985	29	3.50	1985	.04	1978	7.2	3.5	.5	.1	.17	.27	.45	.62	.80	1.00	1.22	1.50	1.88	2.49	3.08
Oct	.95	.70	1.22	1990	20	2.57	1998	.09	1995	5.3	2.6	.4	@	.13	.20	.34	.47	.61	.76	.94	1.15	1.45	1.93	2.40
Nov	.62	.56	1.18	1997	28	2.19	1997	.00	1989	4.6	1.9	.2	@	.01	.05	.13	.22	.32	.44	.58	.76	1.01	1.44	1.86
Dec	.43	.42	.80	1988	15	1.13	1991	.01	1980	4.4	1.6	.1	.0	.03	.06	.11	.17	.24	.32	.41	.52	.69	.96	1.23
Ann	11.51	11.35	2.10	Sep 1985	29	5.14	Aug 1993	.00+	Nov 1989	76.7	34.7	4.2	.6	7.12	7.92	8.97	9.79	10.52	11.24	11.99	12.83	13.86	15.38	16.72

Snow (inches)																							
Snow Totals															Mean Number of Days (1)								
Means/Medians (1)					Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	6.7	3.0	4	2	9.0	1992	7	15.9	1979	18+	1992	7	14	1992	3.9	2.2	.8	.4	.0	9.4	7.2	3.8	.6
Feb	5.5	5.0	3	1	8.0	1989	6	25.1	1989	16	1989	21	12	1992	3.3	1.7	.5	.2	.0	5.5	3.5	2.6	.0
Mar	8.8	8.2	2	#	14.0	1992	4	20.7	1981	24	1992	5	15	1992	4.4	2.8	1.1	.3	.1	4.2	1.6	.2	.0
Apr	5.1	3.1	#	#	10.0	1986	3	18.6	1997	12	1998	3	2	1998	2.8	1.8	.6	.3	@	1.5	.6	.5	.1
May	1.8	.0	#	0	10.0	1999	2	17.5	1999	9	1999	2	1	1999	.9	.5	.3	.1	@	.4	.1	.1	.0
Jun	.0	.0	#	0	.3	1995	9	.3	1995	#	1995	9	#	1995	@	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.1	.0	#	0	2.0	1971	17	2.3	1971	2	1971	19	#+	1996	.1	@	.0	.0	.0	.1	.0	.0	.0
Oct	2.5	.5	#	#	7.0	1972	23	13.5	1972	10	1991	31	1	1998	1.5	.9	.3	.1	.0	1.1	.4	.2	@
Nov	4.9	4.7	1	#	14.0	1997	28	14.0	1997	16	1997	29	5	1991	2.9	1.8	.5	.2	@	5.2	.8	.3	.2
Dec	5.6	6.0	3	1	12.0	1972	12	18.0	1972	20	1991	12	16	1991	3.8	2.2	.6	.2	@	16.1	10.2	7.1	2.0
Ann	41.0	30.5	N/A	N/A	14.0+	Nov 1997	28	25.1	Feb 1989	24	Mar 1992	5	16	Dec 1991	23.6	13.9	4.7	1.8	.1	43.5	24.4	14.8	2.9

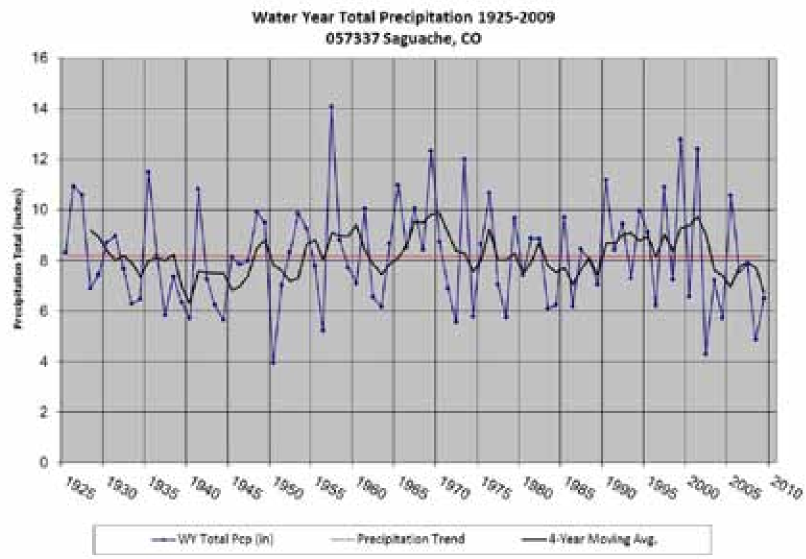

Figure 15. Total water year precipitation from 1925 to 2010 at Saguache, CO (from Striffler 2013).

to a depth of about 40+ feet. This aquifer consists of sands and gravels of the Upper Alamosa Formation historically lying within about 5 feet of the surface in the Upper Sump (Powell 1958). Hydraulic conductivity of this unconfined aquifer can range from 35 to 235 feet/day, with the highest values near the western edge of the SLV. Natural recharge to the unconfined aquifer occurs throughout the SLV from infiltration of precipitation, infiltration of surface water from natural stream channels (i.e., San Luis Creek), inflow of groundwater from the San Juan and Sangre de Cristo Mountains, and upward leakage of groundwater through the confining bed (Powell 1958, McGowan and Plazak 1996, Stanzione 1996). Recharge of the unconfined aquifer is strongly affected by annual changes in runoff from the surrounding mountains, which is a function of annual snowpack and melting dynamics. Loss of water from the unconfined aquifer occurs from ET, discharge to streams and creeks, and some groundwater flow to the south.

Deeper active and passive zone confined aquifers exist below the unconfined alluvial aquifer in the SLV (Fig. 18). Along the periphery of the SLV, the unconfined and active confined aquifers are directly connected hydraulically. The active confined aquifer extends 4,000 feet below the land surface. Recharge to the active confined aquifer takes place, in part, through the unconfined aquifer at these locations through infiltration of precipitation, infiltration of surface water, and inflow of groundwater from the San Juan Mountains on the western boundary of the SLV and from the Sangre de Cristo Mountains near the eastern boundary of the Baca NWR. Discharge from the confined aquifer occurs as groundwater flows to the south and upward leakage through the confining bed.

PLANT AND ANIMAL COMMUNITIES

Baca NWR historically contained a diverse mosaic of vegetation communities. Upland salt desert shrub communities were present across the Sangre de Cristo Mountain alluvial fans. Grasslands became interspersed with shrublands at lower elevations of alluvial fans and were present down to the edges of the Upper Sump and San Luis Creek floodplain. Wet meadow and grassland habitat was present along seasonally inundated floodplains of creeks with some riparian woodland present along at least the upper regions of creeks originating from the Sangre de Cristo Mountains. Many large and small playa lakes/wetlands were present in the Upper Sump area in the nearly level floodplain of San Luis Creek (Hanson 1929; Ramaley 1929, 1942; Harrington 1954; Unknown 1970; Carsey et al. 2003; Madole et al 2008). Vegetation in the SLV historically was highly influenced by infrequent but large late summer rainfall events that usually occurred as monsoonal thundershowers. Most annual plants in the SLV and at Baca NWR germinate and grow, and most perennial plants flower, during the late summer (Carsey et al. 2003). Grasses and sedges begin growing in May, while most new annual plant growth occurs in the SLV after June 1 because freezing weather continues through most of May and light frosts are likely to occur well into June. The surface soils in the SLV usually are dry after snowmelt in March until early summer. Even if soils are not dry in spring, the cold temperatures prevent germination and growth until June. Brief descriptions of the major vegetation communities on Baca NWR are provided below:

Salt Desert Shrub

Upland salt desert shrub communities on Baca NWR historically were present mainly on the alluvial fans that extended from the Sangre de Cristo Mountains to the higher elevation edges of the SLV floor (Figs. 5, 14; Ramaley 1929). Shrub habitats, with interspersed grassland, on Baca NWR can be subdivided based on soil type, groundwater table, and salinity as described below:

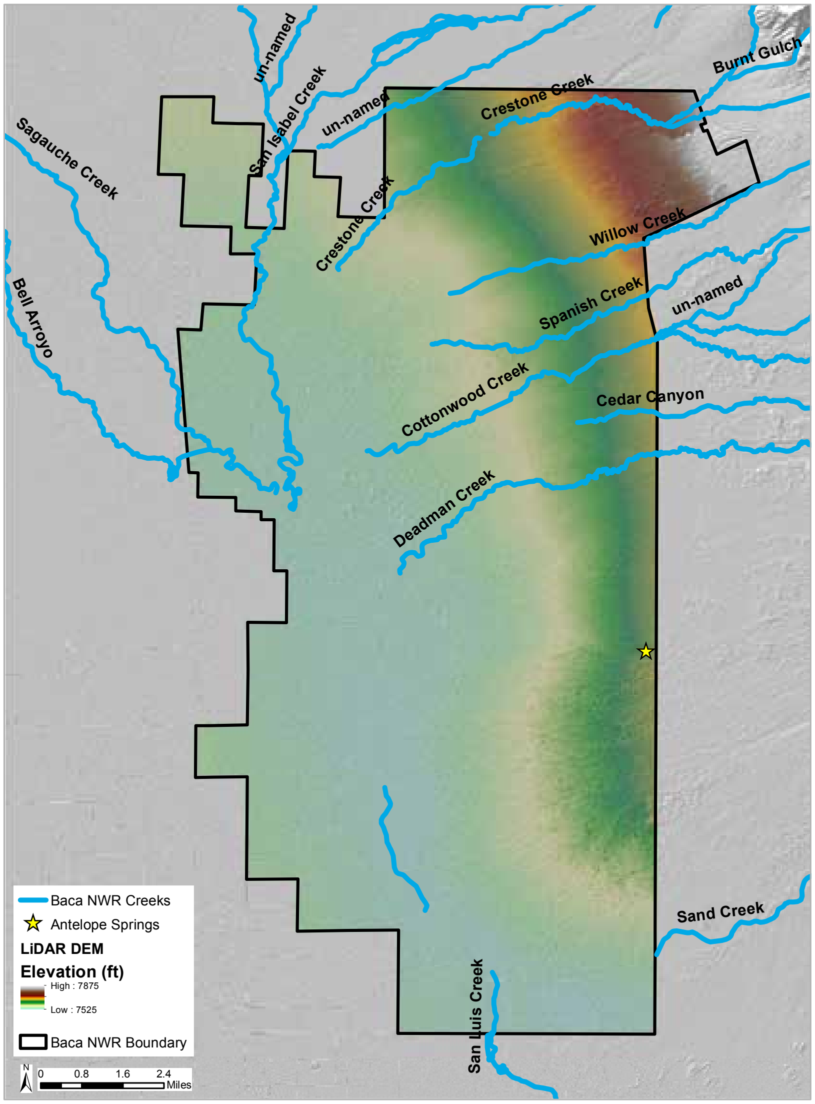

Figure 16. Current location of creek drainages on Baca National Wildlife Refuge.

Saltbush Shrubland and Grasslands

Typically, low salinity loamy sand or sandy loam soils on mountain alluvial fans on the edges of the SLV, such as Space City and McGinty types, support sagebrush, saltbush, and some rabbitbrush that are not highly tolerant of salty soils or long durations of flooding or saturated soils (Ramaley 1929,1942; Tilley et al. 2005; Tilley and St. John 2012). The historical composition of these low salinity shrublands on Baca NWR is unknown. Certain evidence suggests that at least some sagebrush (*Artemisia* spp.) historically was present in at least some areas on alluvial fans in the Baca NWR region (GLO survey notes, Ramaley 1942, Gunnison expedition notes (referenced in Unknown 1970), documented soil-vegetation associations (SCS 1981), Gunnison Sage-Grouse Steering Committee 2005, Boyle and Reeder 2005). However, Baca NWR currently does not contain more than scattered sagebrush, although fourwing saltbush (*Atriplex canescens*), a species that typically occurs in sites that support sagebrush, is present in many areas on the refuge. Upland shrub areas on Baca NWR with low salinity soils historically contained an understory of herbaceous grasses such as alkali sacaton (*Sporobolus airoides*), indian ricegrass (*Achnatherum hymenoides*), and blue grama (*Bouteloua gracilis*) (Ramaley 1942). Low salinity upland salt desert shrub communities were interspersed with larger areas of grassland throughout the alluvial fans and adjacent to the Upper Sump area.

Greasewood and Rabbitbrush Shrubland and Grasslands

Salt desert shrub habitats, dominated by greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Ericameria nauseosa*), historically and currently occur on HHH and SCC soil associations on alluvial fans and terraces (SCS 1981). This shrubland occurs on soils that have a higher salinity with water tables that are commonly close to the surface and may be inundated at times. An herbaceous layer of grasses is commonly associated with this saline shrubland although some

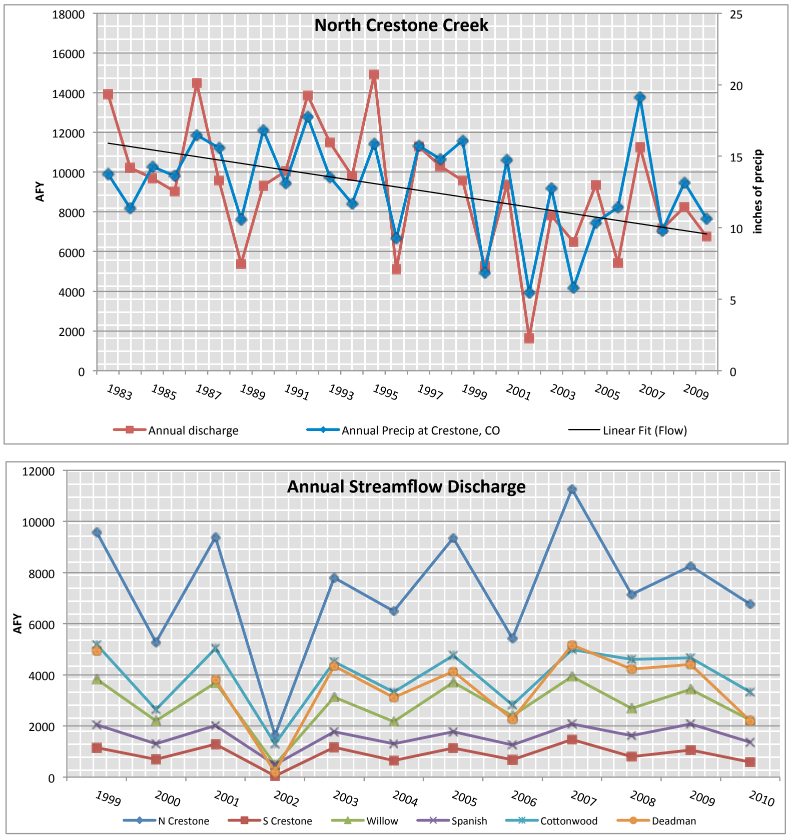

Figure 17. a) North Crestone Creek mean monthly discharge from 1983 to 2009 and b) Annual streamflow discharge from 1999 to 2010 (USGS data from Striffler 2013).

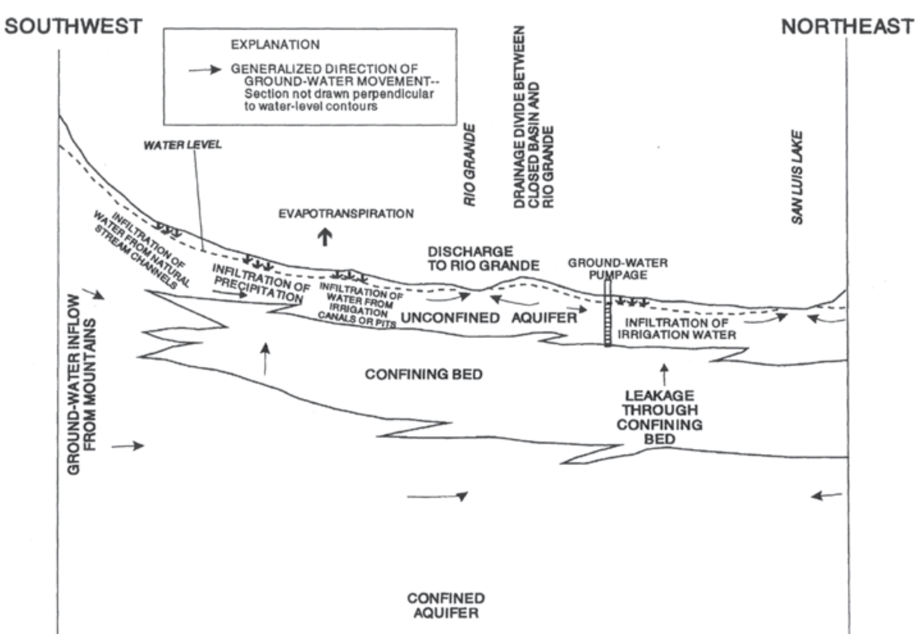

Figure 18. Schematic cross section of groundwater movement in relation to the unconfined and confined aquifers in San Luis Valley, CO (modified from Hanna and Harmon 1989).

areas may only have sparse areas of grass present. Soils in lower elevation shrub areas typically are poorly drained and have groundwater tables that are relatively close to the surface (Cronquist et al. 1977). Even slight differences in elevation can alter drainage and can cause ephemeral or seasonal surface water "ponding", which creates significant variation in soil salinity and consequently heterogeneity in plant species occurrence. For example, excess alkali occurs when water tables are close to the ground surface, especially in shallow depression "pool" areas; these small depression sites typically contain saltgrass, foxtail barley (*Hordeum jubatum*), alkali muhly (*Mulhenbergia asperifolia*), and Douglas' sedge (*Carex douglassii*). Low-lying dune and inter-dunal areas along the southern and eastern portions of Baca NWR were characterized by alkali sacaton (*Sporobolus airoides*) and inland saltgrass (*Distichlis spicata*) with some interspersed greasewood in saline conditions. Where alkali is extremely high, "chico slick spots", or barren salt flats occur within scattered greasewood clumps. Generally more saline subhabitats within the desert shrub area can be determined by salinity of soils (Fig. 13). Tussocks of alkali sacaton occur between shrubs, but ground cover is generally sparse with substantial amounts of bare ground present. The presence of individual herbaceous species is a reflection of soil aeration, seasonal ponding of water in small depressions, and relative depth to groundwater given known root distribution characteristics (e.g., Ramaley 1942).

Dune-bare ground

Natural processes such as wind erosion and deposition created dunelands, or areas devoid of vegetation, in some areas in the eastern and southern portions of the Baca NWR (Fig. 13). These dunelands were created during periods of low water tables with frequent high winds that moved loose sand particles from dry lake beds in the sump area (Madole et al. 2008). These duneland areas have migrated over time depending on climatic conditions. Over time, some dunelands slowly have become re-vegetated with early colonizers including Indian ricegrass, blowout grass (*Redfieldia flexuosa*), and rabbitbrush. In areas with less sand, and more stable soil conditions, a mixture of shrub and grass species such as blue grama, snowberry (*Symphoricarpus* spp.), sand verbena (*Abronia* spp.), and several other species were present (Ramaley 1942).

Grassland

Extensive grasslands historically occurred on Baca NWR in areas adjacent to playa wetlands and some areas on or near the base of alluvial fans where they were interspersed with upland salt desert shrub assemblages. The Gunnison Expedition noted large expanses of "prairies" in the region (Unknown 1970) and settlers throughout the SLV in the 1920s often worked on what is now Baca NWR during the haying season in late summer (Reddin 1979). The grass in this area, regardless of precipitation, provided large amounts of hay that was cut from July through September. The GLO survey also noted that land on the Luis Maria Baca Grant contained "savannah" between creek channels (Fig. 5). Soils in grassland areas include the HHH and SCC associations, especially Gunbarrel and Hooper loamy sand series (SCS 1981). Perennial grasses such as alkali sacaton, western wheatgrass (*Pascopyrun smithii*), and alkali cordgrass (*Spartina gracilis*) were present in these areas and represent potential dominant species that characterized the grassland community.

Riparian Woodland

The historical extent and distribution of riparian woodland on Baca NWR is unknown. Shining willow (also sometimes called whiplash willow, *Salix lucida*), yellow willow (*Salix lutea*), and coyote willow (*Salix exigua*) may have lined some creeks at higher elevations where they entered the valley floor from the Sangre de Cristo Mountains. Shining willow typically occurs along higher elevation creeks and is commonly associated with other species such as coyote willow as an early succession shrub (Carsey et al. 2003). Gunnison's Expedition through the SLV in 1853 spent some time traveling along the eastern edge of the SLV and camped at several points including Chatillon Creek (now called Deadman Creek) (Unknown 1970; Fig. 5). Journal notes indicate that some sporadic cottonwood trees were present along the creek in addition to some willow, however, no other information was found in other historical accounts or from early descriptions of haying operations in the 1920s (Reddin 1979). Landowners in the area also have indicated that some areas along Deadman Creek had a substantial amount of willow prior to the 1980s (Clayton pers. comm.; Keigley et al. 2009).

Wet Meadow

Wet meadows historically were present along the numerous creeks that flowed onto Baca NWR where seasonal flooding occurred from overbank and overland water "sheetflow" events. Historically, the creeks on Baca NWR were ephemeral and flowed from late spring through early summer (Ramaley 1929, 1942) although late summer monsoons may have provided some surface water flow and subsequent recharge. These wetlands may also have been maintained through the groundwater mound formed through recharge by creeks throughout the year. Available groundwater for plants in these wetlands would be variable based on distance from the creek (Wurster and Cooper 2000). Wet meadows at Baca NWR have fine-grained Vastine, Hagga, Medano, and Schrader soils (Fig. 13) that are highly impermeable and lose little water from seepage; most surface water loss occurs from the high summer ET rates. Most wet meadow sites occur directly adjacent to creeks on the north and eastern portion of the Baca NWR. Crestone Creek had the longest contiguous area of wet meadow but a large meadow area also existed between Spanish and Cottonwood Creeks.

Wet meadows at Baca NWR typically were dominated by several species of emergent sedges (*Carex* spp.), spikerush (*Eleocharis* spp.), rushes (*Scirpus* and *Juncus* spp.), dock (*Rumex* spp.), smartweed (*Polygonum* spp.), and millet (*Echinachloa* spp.) (Ramaley 1929, 1942; Carsey et al. 2003). An increase in the water table and short duration shallow flooding tends to promote more saltgrass at the edges of these meadows. The relative juxtaposition of wetland and wet meadow types on Baca NWR likely was dynamic over time depending on periodic movement of the creeks on the area.

Floodplain and Playa Wetlands

The numerous historical creek corridors converging on the Baca NWR included active and relict stream channels and their floodplains. Remnant creek channel depressions are present throughout the refuge and these wetlands contain diverse communities of sedges, rushes, and grasses along with some annual plants such as goosefoot (*Chenopodium* spp.) and smartweed (*Polygonum* spp.) (Ramaley 1929, 1942; Carsey et al. 2003). Aerial photos from 1941 and recent aerial photos (Figs. 6, 19) show some water present in these wetlands throughout the summer at least during wet years within old lake basins. This information coupled with botanic inventories conducted by Ramaley (1929, 1942) indicate that semipermanent flooding regimes were historically present in some years in at least the larger deeper "distinct" playa basins present in the Upper Sump area. Gunnison's Expedition recorded relatively large marshes in the Baca NWR area that made travel difficult from east to west making it necessary to travel along the eastern edge of the SLV north of the town of Crestone before going west (Unknown 1970). A map of Wheeler's Expedition in the late-1800s indicates that herbaceous wetlands and irrigated land were the dominant habitats along creeks on Baca NWR (Fig. 20).

Vegetation in playa wetlands is adapted to seasonal and inter-annual flooding and drying dynamics. Playas in the Baca NWR region historically received surface water inputs in spring following snowmelt, during summer following monsoonal rain runoff, and occasionally in winter when warm temperatures caused some snowmelt. Periodic drying of playas in summer and in dry years allowed winds to remove salt accumulations and in essence "freshened" the basins. During the driest years, the water table lowered and playas became dry or very shallow. Greasewood and rabbitbrush encroached toward the center of the lake, and monotypic stands of saltgrass could cover entire lake beds (Ramaley 1942). During wet years, surface water expanded and inundated shrubs as evidenced by greasewood skeletons observed underwater by Ramaley in 1942, which shifted the community to plant species more tolerant of flooded conditions. If water and weather conditions remain consistent over several years distinct wetland vegetation zones become established from the margins to the interior of playa lakes. The deepest or inner areas of playa lakes support perennial and emergent plants such as scarlet smartweed (*Persicaria coccinea*) and pondweed (*Potamogeton* spp.) transitioning to bulrush (*Schoenoplectus tabernaimontani*) and spikerush becoming dominant towards the shoreline. Plants tolerant of higher salinities often occur in bands beyond the spikerush and include species such as alkali buttercup (*Ranunculus cymbalaria*) and silverleaf cinquefoil (*Argentina anserina*) (Ramaley 1942). The now globally endangered slender spider flower (*Cleome multicaulis*) also was present in some areas and was present adjacent to expanding bands of saltgrass, sand dropseed (*Sporobolus cryptandrus*), and western wheatgrass along with some sedges and rushes (Ramaley 1942).

Key Animal Species

A diverse assemblage of animal species historically was present in the various habitat types on the Baca NWR and adjacent lands (Rocchio et al. 2000). For example, shrublands support about 100 species of birds including many obligate species such as the endangered Gunnison sage grouse (*Centrocercus minimus*) (Tilley et al. 2005). Grassland and shrub bird species such as Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), sage thrasher (*Oreoscoptes mantanus*), savannah sparrow (*Passerculus sandwichensis*), and western meadowlark (*Sturnella neglecta*) probably used many of the grassland and shrub habitats in the refuge area. Small mammals such as the desert cottontail (*Sylvilagus auduboni*), white tailed jackrabbit (L*epus townsendii*), long tailed weasel (*Mustela frenata*), and northern pocket gopher (*Thomomys talpoides macrotis*) regularly use shrublands and their herbivory and presence helps maintain a heterogeneous vegetation structure and other habitat features such as burrow holes required

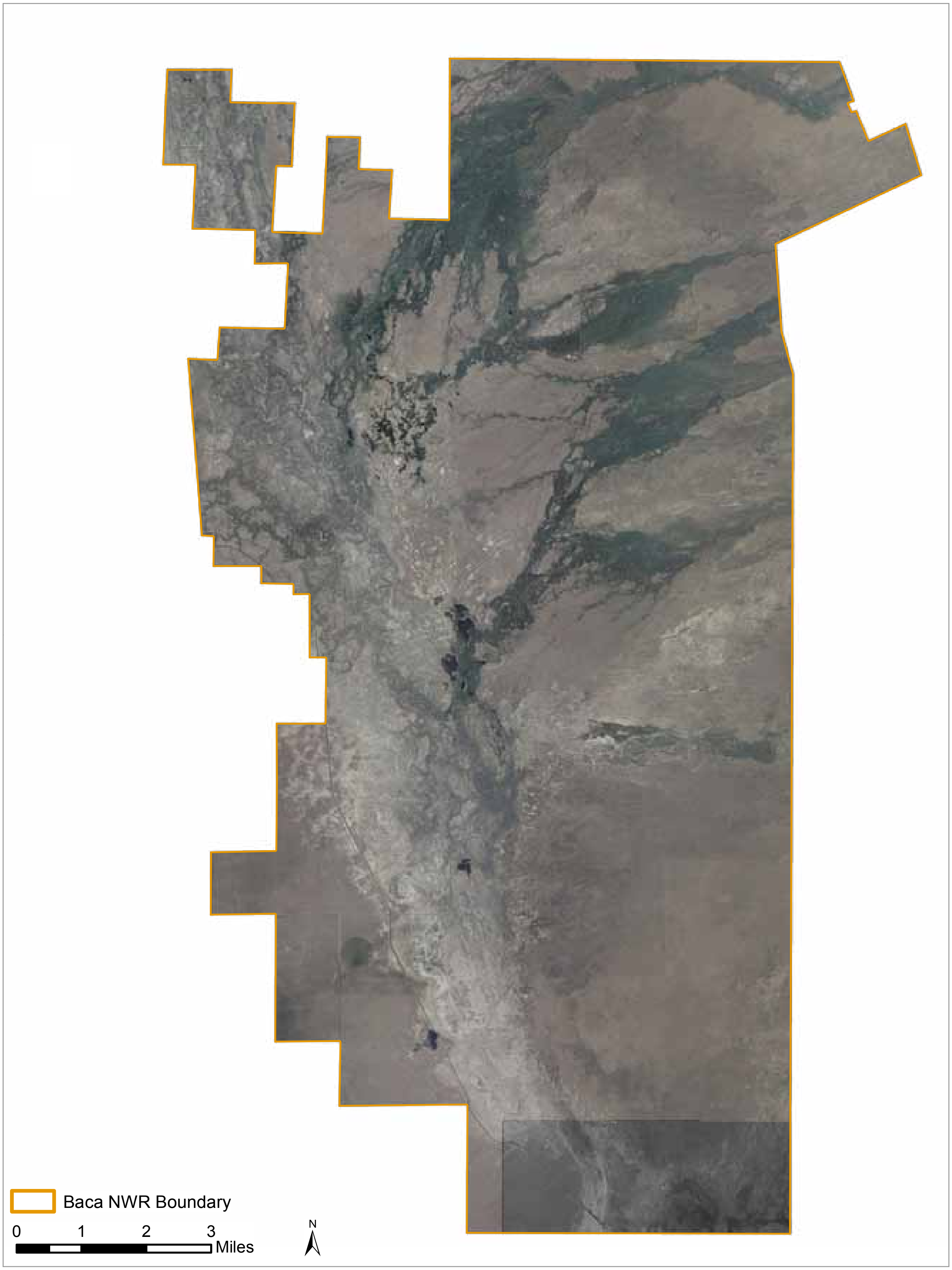

Figure 19. 2011 Aerial photo of Baca National Wildlife Refuge (NAIP from. USDA/NRCS Geospatial Gateway).

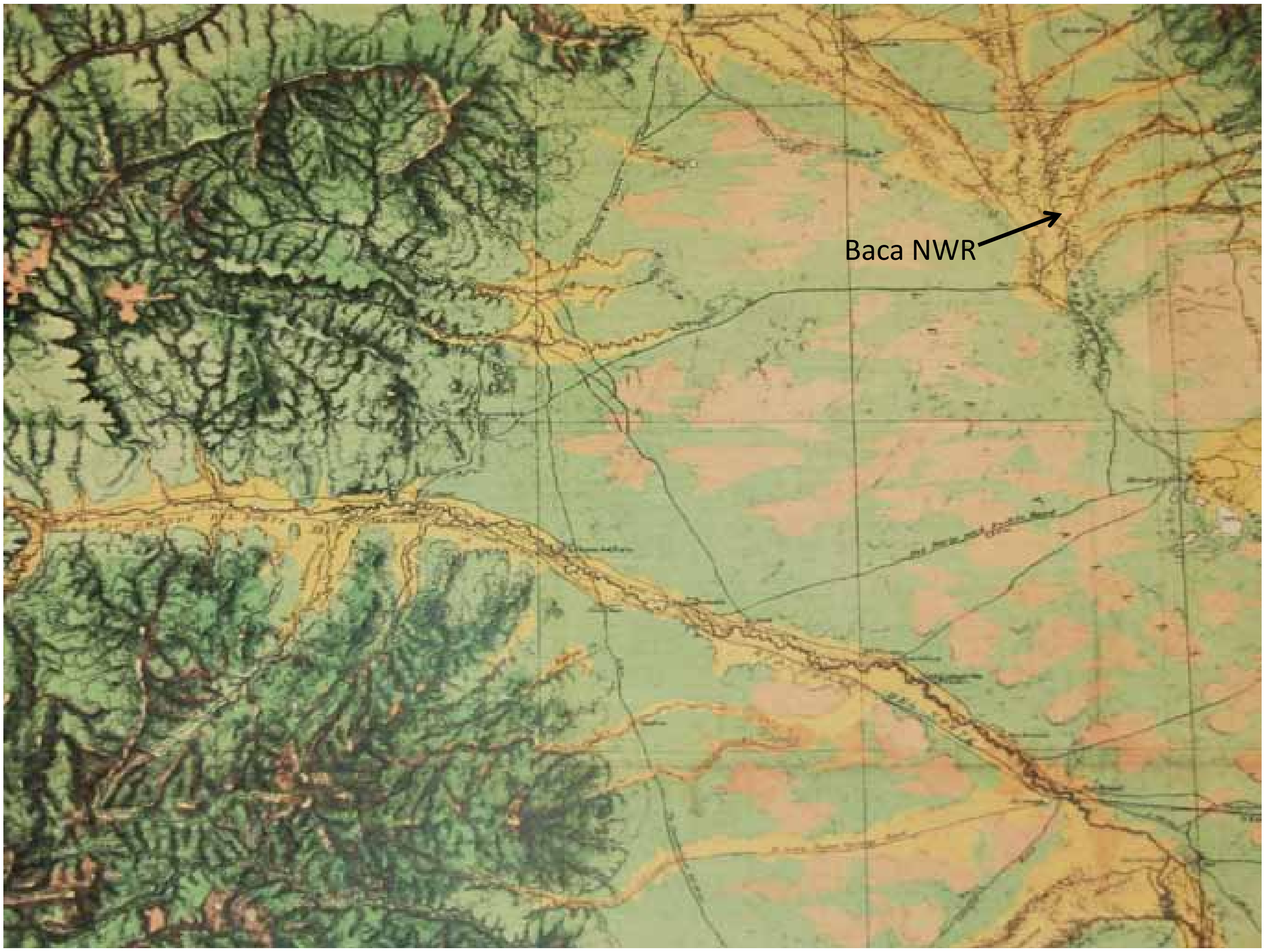

Figure 20. Wheeler Geologic Map of the San Luis Valley depicting land coverages. Yellow= Agricultural (irrigated); Pink= Arid and barren; Light green= Grazing; and Dark green= Timber. From U.S. Geological Surveys West of the 100th Meridian Land Classification Map of Southwestern Colorado: Expeditions of 1873, 74, 75, and 76. Atlas Sheet No. 61 (USFWS files).

by burrowing owls (*Athene cunicularia*) (Colorado Natural Heritage Report 2010). Ungulates such as pronghorn (*Antilocapra americana*), mule deer (*Odocoileus menionus*), elk (*Cervus canadensis*), and bison (*Bison bison*) historically were common and utilized many of the shrubs for winter forage as well as grasslands and wet meadows during the growing season.

The alternating inter-annual wet and dry precipitation patterns in the SLV caused the availability of wetland habitats to be highly variable among years. The wet meadows and grasslands supported many waterbird, mammal, and amphibian/reptile species, especially during wet years when more stream flow and overbank flooding filled seasonal wetlands and playa lakes. Perennial streams, discharge from Antelope Springs, and precipitation events during wet years may have helped maintain high water tables and surface water, and subsequently sheet ice, on playa wetlands during winter. Most waterbirds probably used the historic wetlands present on Baca NWR during spring and fall migration with some breeding occurring dependent upon annual climatic conditions (Hopper et al. 1975). Common species utilizing this area probably included waterfowl, shorebirds, and wading birds such as dabbling ducks, common snipe (*Gallinego gallinego*), American avocet (*Recurvirostra americana*), long-billed dowitcher (*Limnodromus scolopaceus*), various sandpipers (*Caldris* spp.), white-faced ibis (*Plegadis chihi*), and snowy egrets (*Egretta thula*) (Hopper et al. 1975). Amphibians and reptiles such as the western terrestrial garter snake (*Thamnophis elegans*), northern leopard frog (*Rana pipiens*), plains spadefoot toad (*Scaphiopus bombifrons*), and Great Plains toads (*Bufo cognatus*) frequented wetland areas. Explorer accounts document a surprisingly large amount of trout in the streams originating in the Sangre de Cristo Mountains as well as post settlement observations of the Rio Grande sucker (*Catostomus plebeius*). The state endangered Rio Grande sucker (*Catostomus plebeius*) also was observed in the creeks located in the area previously known as the Baca Ranch (USFWS 2005).

Historical Distribution and Extent of Plant Communities

We developed an HGM matrix of known relationships of major plant communities on Baca NWR to geomorphic surface, soil, general topographic position, and hydrology (Table 3). Information from this matrix also was used to prepare a map of the potential distribution of communities that may have existed on Baca NWR in the late-1800s (Fig. 21). The HGM relationships in the matrix were based on general plant communities described and mapped in the late-1800s by the GLO surveys (Fig. 5), plant species associations described in published literature (e.g., Ramaley 1929, 1942; Harrington 1954; Cronquist et al. 1977), older maps (Wheeler 1887, Siebenthal 1906, Clason 1910, Fig. 20), aerial photographs (Fig. 6), and contemporary understanding of plant species relationships (i.e., botanical correlation) to geomorphology, soil, topography and elevation, hydrological regimes, and ecosystem disturbances in the SLV (e.g., Carsey et al. 2003, Brown et al. 2007, Robbins 1910, Summers and Smith 1927, Ramaley

Table 3. Hydrogeomorphic (HGM) matrix of historic distribution of vegetation communities/habitat types on Baca National Wildlife Refuge. Relationships were determined from old aerial photographs, plat and GLO maps, geomorphology maps, soil maps, and survey publications (SCS 1980), various historical botanical accounts of the region (Hayden 1873, Hanson 1929, Ramaley 1929, 1942, Carsey et al. 2003) and land cover maps prepared by the U.S. Fish and Wildlife Service.

Habitat Type	Geomorphic surface	Soil Association	Soil Type	Flood Frequency[a]
Wet meadow	Floodplain margins, terrace	HHH	Hagga, Medano, Schrader, Vastine	SWF
San Luis Creek Floodplain and Playas	Old lake beds, floodplains	BBG, HHH	Biedell clay loam, Hooper clay loam, Hooper occasionally flooded, Hapney clay loam	SWF
Distinct Playas	Old lake beds, floodplains	BBG, HHH	Biedell clay loam, Hooper clay loam, Hooper occasionally flooded, Hapney clay loam	SWF
Dunes -bareground	Duneland	SCC	Duneland	
Grasslands	Floodplain margins, alluvial fan, terrace	HHH, SCC	Harlem, Hooper loamy sand, Laney, Kerber, Mosca, Crestvale, Gunbarrel loamy sand, San Luis sandy loam, Cotopaxi	OSL
Saltbush shrublands and grassland	Dunes, Alluvial fan, hills	HHH, SCC	Space city loamy sand, Hopkins, Jodero, McGinty sandy loam	OSL
Greasewood and rabbitbrush shrublands and grassland	Alluvial fan, terrace	HHH, SCC	Space city loamy sand (saline), gunbarrel loamy sand (saline), Arena, Hapney loam, San Luis, Corlett-Hooper complex, Travelers	OSL

[a] OSL – on-site local precipitation, SWF – surface sheetwater flow.

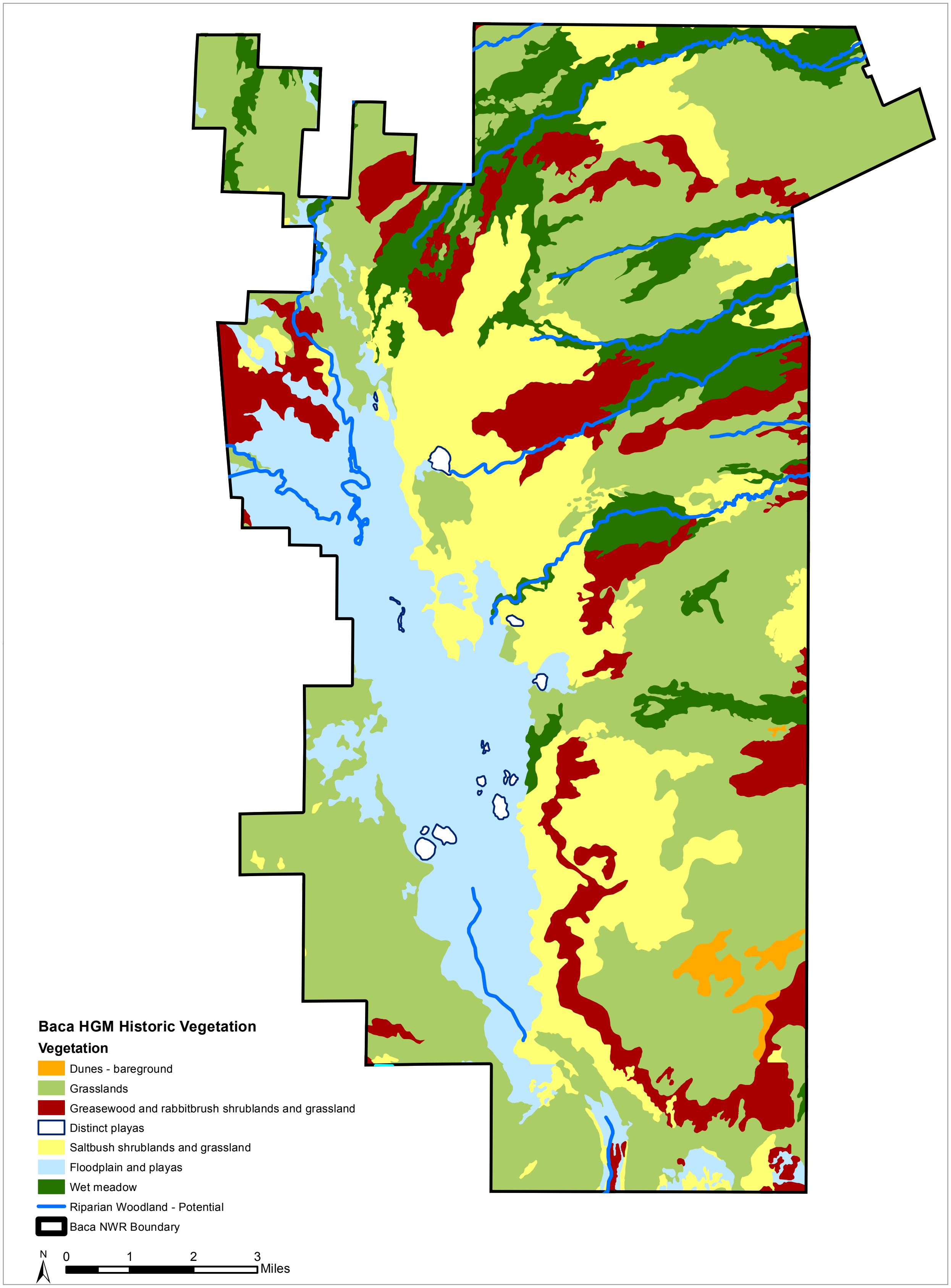

Figure 21. Distribution of HGM-derived potential historic vegetation communities on Baca National Wildlife Refuge.

1929, 1942, Hanson 1929, Harrington 1954, SCS 1981). These plant-abiotic correlations are, in effect, the basis of plant biogeography and physiography whereby information is sought on where plant species, and community assemblages occur relative to geology and geomorphic setting, soils, topographic and aspect position, and hydrology (e.g., Allred and Mitchell 1955, Barbour and Billings 1991, Bailey 1996).

Relationships identified in the HGM matrix provide an objective method to map the potential distribution of vegetation communities historically present; however, predictions regarding the type and historic distribution of communities are only as accurate as the understanding and documentation of plant-abiotic relationships and the geospatial data for the abiotic variables for a location and period of interest. For example, mapping the precise location of all shallow small wetland depressions that were interspersed within dunes on Baca NWR during the Presettlement time is not possible because these small wetland areas shifted location continuously over time due to wind and water erosion or dune movement. Also, substantial alterations to regional hydrology have occurred on Baca NWR and the surrounding area since the mid-1800s from construction and subsequent operation of dikes, ditches, canals, and water-control structures. Consequently, the potential historical vegetation map (Fig. 21) should be seen as a "hypotheses" of community distribution based on the best available data at this time.

Using the HGM information described above, the major factors influencing the type and distribution of historical vegetation communities at Baca NWR are:

1. The geomorphic and topographic surfaces created by wind and major creeks that cross Baca NWR including historical wetland depressions associated with the floodplains based on GLO maps and survey notes, historic maps, and documented observations (Figs. 5, 6, 9, 20).
2. Location of wetland and riparian areas (Figs. 5, 6, 20)
3. Soil type and salinity (Fig. 13).
4. On-site hydrology that is affected by type and input of surface and groundwater from creeks, precipitation, seeps, springs, and sub-irrigation.

The first step to develop the HGM matrix and potential historical vegetation map specific for the Baca refuge was to determine the distribution of major vegetation/community types from GLO surveys (Fig. 5), early botanical accounts (e.g., Ramaley 1929, 1942), and older maps, aerial photographs, and accounts (Figs. 5, 6,16, 20). This information defines the locations of the historic North and South Crestone, San Luis, San Isabel, Willow, Spanish, Cottonwood, Deadman, Saguache, and La Garita creeks. Other descriptions include the location of the Upper Sump area, sagebrush habitats, and dune systems (e.g., Figs. 2,4,5). These major landscape and vegetation features were overlaid on contemporary geomorphology, soil, and topography maps to determine correspondence. While older maps and accounts have limitations and may not be accurately georeferenced, they do provide the opportunity to specifically define some areas, such as the larger playa lakes in the Upper Sump. These playas are located on clay loam soils including the Biedell clay loam and Hapney clay loam, while dune systems east of the playa lakes were associated with Cotopaxi, Space city, and Duneland soils series (Table 3; SCS 1981). Information in the 1981 soil survey for Saguache County was especially useful to distinguish major communities associated with specific soil types and series (SCS 1981). We acknowledge that soil mapping in 1981 may have reflected changes in the soil chemistry and hydrologic characteristics that occurred because of extensive irrigation since the late-1800s. Although roads, ditches, canals, and haying operations were established by the 1920s, the basic topography of the area can still be discerned on photographs and maps and are easily linked with the soils mapped to the area.

For the late-1800s potential vegetation map, wetland habitats were separated into wet meadow and playas as identified by historic maps and GLO surveys (Figs. 4, 5, 6, 20), historic accounts, and soil survey in relation to hydrologic regime and topography (Fig. 13). Wet meadows are dominated by Vastine, Hagga, Medano, and Schrader soils, which have shallow seasonal flooding regimes and contain a variety of loam soils (Table 3; Fig. 13). Playa areas occur on BBG soils and are concentrated in the lowest elevation areas where wind deflated basins occur and groundwater is closer to the surface (Figs. 2, 4, 13). Distinct playa areas designated in Fig. 21 represent some of the larger playas but not all of them. Many playas are located throughout the BBG land association and are mostly contained to the Upper Sump and along San Luis Creek.

Grassland historically was located on the alluvial fans between creeks and was interspersed with salt desert shrub areas on Baca NWR and adjacent to the Upper Sump area. Grass areas were most commonly associated with HHH and SCC soil-land associations that contained some component of sand such as the Hooper loamy sand and Gunbarrel loamy sand (Fig. 13). Gunnison's Expedition and early-1900s accounts indicate that grassland covered large expanses and were about one foot tall in dry years and 2.5 feet tall in wet years (Reddin 1979; Unknown 1970). Shrublands dominated by greasewood at Baca NWR were located in upland areas with more saline soils such as Arena and Gunbarrel loamy sand saline soil types.

The location of shrub and grass areas may have expanded or contracted as weather conditions changed over time and as water tables fluctuated. Undoubtedly, some areas contained a mix of shrub and grass species, which sometimes currently are referred to as "transition" habitats. The relative historical species composition of salt desert shrub and grassland habitat at Baca NWR undoubtedly varied considerably depending on site-specific soils, hydrology, topography (Ramaley 1942), and seral stage. For example, dune areas east of playas in the Upper Sump were formed by temporally dynamic wind erosion and deposition, which created distinct site-specific conditions in hydrology, soil structure, and elevation that ultimately determined the composition and distribution of shrub species. The GLO survey and existing soils associations and series indicates that shrublands and grasslands existing in the eastern portion of Baca NWR were heterogeneous in composition and location. Shrubs apparently included some unknown amount of sagebrush, rabbitbrush, and greasewood. Sagebrush is adapted to a range of soil, salinity, pH, and moisture conditions making it resilient to drought conditions and moderate salinity, but not to a high water table (U.S. Department of Agriculture 2002). Greasewood and rabbitbrush have some similar characteristics although their relative distribution can be differentiated to some degree by soils, hydrology, and disturbance. Greasewood prefers fine soil textures and can withstand long periods of flooding and high salinities (Benson et al., unknown date), whereas rabbitbrush is an early seral species that often becomes established in recently disturbed areas with sandy soils that are less frequently flooded (Scheinost et al. 2010). Older botanical accounts indicate interspersion of highly saline barren "chico" flats and pans at Baca NWR along with ephemeral wetland basins (Ramaley 1929, 1942). Unfortunately, contemporary alteration of hydrology and the long-term grazing and haying history at Baca NWR make mapping the potential historical distribution of these interspersed alkaline wetland pans difficult.

The extent of the historical riparian area along the creeks at Baca NWR is largely unknown, but the distribution of seasonally hydrated soils may have been suited for at least some cottonwood and willow survival and growth (see Cooper et al. 1999, Scott et al. 1993, 1999). It seems likely that narrow riparian woodland habitats may have existed along at least the higher elevations reaches of some creeks before they entered the valley floor. In these reaches, periodic pulses of discharges following snow melt formerly scoured riverbank surfaces, deposited silts on natural levees, and created substrates suitable for regeneration, growth, and survival of cottonwood and willow (Scott et al.1993, 1999). The location of riparian habitats likely shifted frequently following flood periods that created or destroyed suitable substrates for tree germination and survival. Studies including Keigley et al. (2009) and Schoenecker et al. (2005) indicate that willow readily becomes established near creek channels on Baca NWR where browsing has been controlled by fenced exclosures. Further, many of the dead willow now on the refuge appear to be several decades old and conversations with past land managers, some with over 40 years' experience working on the Baca, indicate that some stream courses such as Deadman Creek had extensive willow galleries (Keigley et al. 2009, Eddie Clayton personal communication). Locations of historical riparian woodland galleries are represented by creek drainages on the HGM potential vegetation map, as they were probably immediately adjacent to the creeks and of limited width (Fig. 21). In addition, these riparian zones probably were continuously shifting over time as creek channels moved across the alluvial fans.

CHANGES TO THE BACA ECOSYSTEM

SETTLEMENT AND EARLY LAND USE CHANGES

Native people apparently first occupied the SLV 10,000 to 12,000 years BP (e.g., Jodry et al. 1989). These people had a highly mobile lifestyle that depended largely on big game hunting. Native people continued to occupy the SLV thereafter, but populations apparently were relatively small with localized and often seasonal settlements. Many of these camp sites and population centers were along the Rio Grande and former lakes, rivers, and wetlands of the SLV because of the more predictable availability of water, wildlife, and shelter. Inhabitants of the area collected wild plants, hunted large and small animals, and created chipped and ground tools. By about 2,000 BP, human populations in the SLV appear to have increased and small villages were established; evidence of early agriculture is found along some waterways. Pueblo people were attracted to the SLV and they, along with the Comanche, Utes, and other tribes, maintained some occupation of the region through the mid-1800s. Surveys conducted by the Colorado Natural Heritage Program indicate that some areas on the Baca NWR were used extensively by early people (Fig. 22).

Spanish settlers first entered the SLV between 1630 and 1640 and several Spanish expeditions to the SLV occurred in the 17th and 18th centuries, although extensive settlement did not occur until the 1800s. An excellent summary of European settlement and history in the SLV is provided in Athearn (1975) and Simmons (1999), as excerpted from USFWS 2003. The following historical information comes from these sources unless stated otherwise.

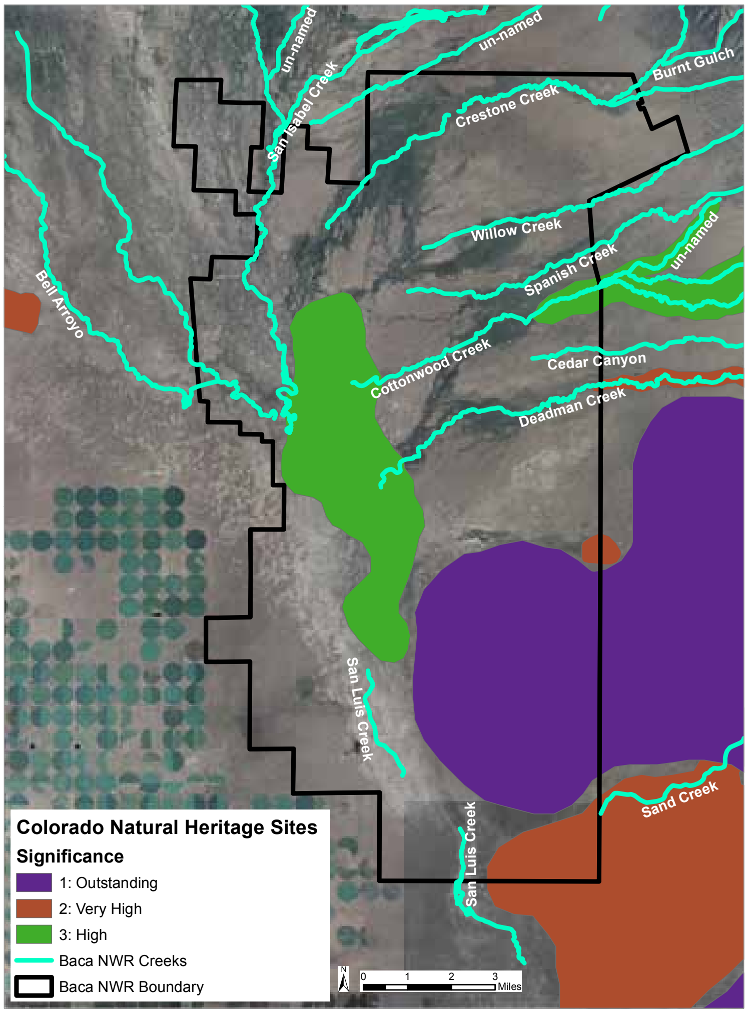

Figure 22. Location of Colorado heritage sites on Baca National Wildlife Refuge.

The historic territory of "New Mexico" was claimed for Spain in 1598 and Juan de Onate established a base near the confluence of the Rio Grande and Rio Chama. Shortly thereafter, hunting and exploratory expeditions into the SLV occurred including bison hunts by native people (Fitzgerald et al. 1994). Santa Fe was established in 1610 and became the capital of Spain's Northern Province.

Conflicts between the Spanish, Pueblo, and Ute people accelerated in the early- to mid-1600s. After expulsion of Spanish people from New Mexico in 1680, Spain retaliated in 1694, when Don Diego de Vargas re-established control of Santa Fe. Later de Vargas traveled through and established camps in the SLV to hunt bison and elk. Many place names in the SLV came from early Spanish expeditions and people. By the mid-1700s the Comanche gained power in the Rio Grande Valley and displaced the Ute who lived in the SLV. During the mid- to late-1700s, the controlling government of New Mexico attempted to curtail Comanche raiding parties in the region, including the SLV. The Utes joined the Spanish in combating the Comanche and in 1786, the Comanche were defeated and signed a peace treaty with the Spanish. From 1780 to the early-1800s, the Utes were the principal claimants to the SLV and Colorado mountains. Other tribes including the Navajo, Apache, Comanche, Kiowa, Arapaho, and Cheyenne also visited the valley. Spanish and native people began to trap for furs in the nearby mountains at this time and the fur trade expanded markedly after the U.S. gained control of much of the western U.S. via the Louisiana Purchase. Zebulon Pike was dispatched to explore the Rocky Mountain region in 1806. His party established a winter camp along the Conejos River, where he was captured and detained by the Spanish government for not having authorization to be in Spanish territory, resulting in cutting short his exploration efforts. This was the last U.S. sponsored expedition into the SLV until 1848, when John Fremont came through the valley in search of a route through the Rocky Mountains.

In 1821, revolution created the independent Republic of Mexico, which then became separated from Spain. At this time the former New Mexico territory became a free province and American and Mexican trappers regularly used the SLV as a resting and staging location. While the buffalo trade developed across the west in the 1830s, the SLV was less affected because it had few bison and the Utes defended their hunting territory.

No permanent town-settlements occurred in the SLV until the 1800s. Hispanic settlement of the SLV began on Mexican land grants in the 1840s and early-1850s, comprised mainly of Spanish missionaries and sheepmen (Buchanan 1970). Farmers soon learned that the rivers and creeks were the only areas that could be cultivated and these riparian and floodplain areas also provided the most dependable forage for livestock, which dominated the economy of the area at the time (Holmes 1903). By the late-1840s, scattered settlements were present throughout the SLV. In 1846, war occurred between Mexico and the U.S., culminating in the Treaty of Guadalupe-Hildalgo in 1848 when the U.S. obtained control over Colorado and other western areas. After the U.S. occupied the Southwestern region, a network of army posts were established and settlement, farming, and ranching expanded rapidly in the late 1850s. The Homestead Act of 1862 and the arrival of roads and railroads in the 1860s and 1870s facilitated substantial population growth. During the 1860s a series of roads were built in the SLV to facilitate travel north from Fort Garland and the Ute people were given a large reservation on the western slope of the Colorado River. Along the Sangre de Cristo range, mines and small towns were common. The first prospecting for precious metals occurred on Cottonwood Creek in 1875, and was partly responsible for the establishment of the town of Crestone. In 1879 a narrow gauge rail line was constructed to Alamosa, Colorado and agricultural goods were shipped to Denver, Colorado and other eastern cities. By the late-1800s sheep and cattle grazing were extensive in the SLV with farms producing large quantities of potatoes, hay, and peas. Small roads became well established throughout late-1800s and early-1900s across what is now the Baca NWR and adjacent public lands in order to facilitate travel from the Mosca/Hooper area to the mountains for wood gathering (Reddin 1980). A road labeled as the Liberty Road was a common route taken up to Short Creek where wood was gathered (map by Lovato in Reddin 1980).

Following major expansion of settlement into the SLV in the mid-1800s, farmers decided that irrigation was necessary to support local agricultural production. The history of efforts to develop means to irrigate SLV lands for agricultural production is extensive and is a classic example of efforts to acquire, divert, and use limited surface and groundwater in the western U.S. (Siebenthal 1910, Follansbee et al. 1915, Brown 1928, Powell 1958, Buchanan 1970, Emery et al. 1973, Athearn 1975, Hanna and Harmon 1989, Leonard and Watts 1989, BLM 1991, Ellis et al. 1993, Emery 1996, Jodry and Stanford 1996, McGowan and Plazak 1996, Wilkins 1998). This report does not attempt to chronicle the complex water developments, laws and regulations, and past and current attempts to plan and manage irrigation water supplies and diversions in the SLV. However, the following is a brief account of some of the major events that ultimately affected water supplies, movement, and uses on Baca NWR based on the above references.

The first ditch to move water from local rivers to the interior of the SLV occurred in 1852, with the San Luis Peoples Ditch. The first large ditch to move water from the Rio Grande, the Silva Ditch, was constructed in 1866 (Holmes 1903). The "Ditch Boom" hit the SLV in the 1880s when many British and eastern investors sponsored construction of canals to provide irrigation water to agricultural areas in the SLV. The largest investments came from the Travelers Insurance Company of Connecticut, which financed the building of the Monte Vista and Travelers canals that diverted water from the Rio Grande to various areas of the SLV. The largest of the canals constructed was the Rio Grande Canal completed in 1884, which diverted approximately 30% of the water in the Rio Grande to service Alamosa, Rio Grande, and Saguache counties (Bauman 2001). Other major canals subsequently were built in the 1880s, transforming the valley floor into a major agricultural production region.

Agricultural production in the SLV was enhanced by drilling thousands of wells into both the shallow unconfined and the deeper confined aquifers in the late-1800s. Wells drilled into the unconfined aquifer are subject to annual variation related to variable recharge rates from infiltration of local precipitation and runoff, whereas wells drilled into the confined aquifer have "artesian" flows whereby groundwater free-flows upward from hydrostatic pressure in unconsolidated material. Recharge of the unconfined aquifer may be artificially increased by the addition of groundwater resources from beneath the confining layers being applied to the surface for irrigation. By 1980 about 2,300 pumped wells were present in the unconfined aquifer in the SLV (Emery 1996). Artesian water in the SLV was discovered about 1887 and within four years about 2,000 flowing wells had been developed (Emery 1996). By 1904 more than 3,200 artesian wells had been drilled and by 1916 about 5,000 artesian wells were flowing in the SLV. By 1970 that number had increased to over 7,000 wells. Well pumping typically causes the unconfined aquifer to be seasonally lowered; the last time this aquifer was at or near capacity was the mid-1980s and the mid-1990s. Pumping from the confined aquifer has continually depleted the aquifer storage and it has not been at capacity since the early-1950s (http://www.waterinfo.org/taxonomy/term/1620).

The substantial diversion of water from the Rio Grande in the SLV in the late-1800s led to an "embargo" of 1896 and the Rio Grande Convention Treaty of 1906 between the United States and Mexico. The "embargo" ordered by the U.S. Secretary of the Interior prevented further irrigation development of any magnitude in the Rio Grande Basin of Colorado and New Mexico by suspending rights of way across public lands for use of Rio Grande water; the embargo was not lifted until 1925. Under terms of the Treaty of 1906, the U.S. guaranteed an annual delivery in perpetuity of 60,000 acre-feet of water in the Rio Grande at the head of the Mexican Canal near El Paso, Texas. In 1929, a temporary compact for water use and delivery in the Rio Grande was ratified by Colorado, New Mexico, and Texas and in 1938-39 these states ratified the Rio Grande Interstate Compact, which provides for apportionment of the water of the Upper Rio Grande Basin on the basis of specified indexes of flow at key gauging stations (Rio Grande Compact Commission 1939). This Compact greatly influenced diversion of water from the Rio Grande in the SLV and subsequent development of surface and groundwater infrastructure. Actions to meet Compact regulations in the late-1960s caused major changes in the timing, distribution, and availability of water resources throughout the SLV (e.g. Emery 1996).

The hydrology of the SLV was substantially altered beginning in the late-1800s as surface water and subsequently groundwater was used to irrigate large expanses of land. This irrigation created an artificially high water table creating salinity issues and the need for many areas to be drained (Thomas 1963). The 1938 Natural

Resource Joint Investigation Report (Natural Resources Committee 1938) indicated that the amount of land being sub-irrigated in the SLV had increased substantially by that time and that this subirrigation was altering native vegetation communities while simultaneously increasing the water table and alkalinity. As center-pivot sprinklers became the primary type of irrigation for crops, sub-irrigation declined along with rapid depletion of groundwater resources (Emery et al. 1973, Emery 1996). In 1936, grasslands and pastures were the only irrigated crop types located on lands now contained within Baca NWR (Fig. 23). At Baca NWR, many areas of former grasslands and some shrublands on higher elevation alluvial fans near creek channels were converted to wet meadows for livestock grazing and production of hay and cropland via extensive networks of irrigation infrastructure built in the late-1800s and early-1900s. Much of this early water-control infrastructure remains present and functional on the Baca NWR in the form of the historic Baca ditches and diversions on creeks originating from the Sangre de Cristo Mountains (Fig. 24). Irrigation occurred in all of the different historical vegetation types including shrublands, grasslands, wet meadow, and playas present on a variety of soil types (Fig. 23).

The Closed Basin project was proposed in 1936 (Natural Resource Committee 1938), but authorization and construction of infrastructure were not initiated until the 1970s. A series of 170 shallow groundwater wells were drilled "for the principal purposes of salvaging, regulating, and furnishing water from the closed basin area of Colorado; transporting such water into the Rio Grande; making water available for fulfilling the United States obligation to the United States of Mexico in accordance with the treaty dated May 21, 1906" (Public Law 92-514 – Oct. 20, 1972) through a conveyance canal constructed in the Closed Basin area along the eastern portion of the SLV originating just outside the Baca NWR and roughly paralleling its western boundary (Figs. 2, 24). For an in-depth description of the project proposal, purpose, construction, and implementation please see Geohydrology of the San Luis Valley, San Luis Valley Project, Closed Basin Division, Colorado, and Rio Grande Decision Support System (RGDSS) Feasibility Study, among others (Emery 1979, U.S. Bureau of Reclamation Unknown date, Riverside Technologies, Inc. et al 1998). In the early-1970s, the Colorado State Engineer placed a moratorium on new wells drilled into the confined aquifer in the SLV. Since 1981, no well construction permits for new water appropriations, other than exempt domestic wells, have been issued throughout the entire SLV.

CONTEMPORARY HYDROLOGICAL AND VEGETATION COMMUNITY CHANGES

Water Sources

The primary land use now in Baca NWR, prior to its establishment as a NWR, was for hay production and cattle or sheep grazing (Dieni 2010a,b; Murphy 2009; USFWS 2005). To enhance hay production on this property, a "catch and redistribute" irrigation system was developed (Eddie Clayton personal communication). Creek water was diverted through ditches and then discharged at the highest points in the wet meadows. Unused water was captured in the low spots of the meadow and redistributed to the next high point where the process was repeated. Haying typically was completed in late summer and grazing of these areas occurred during fall and winter. Management of the Baca NWR area using this water diversion system has been relatively consistent over the last 125 years (Murphy 2009; refuge staff personal communication). During the 20 years immediately prior to refuge acquisition, the maintenance and repair of water-control infrastructure generally was neglected and ditches and levees had to be repaired, cleared, or plugged annually (Eddie Clayton personal communication). The aging water-control infrastructure could not efficiently deliver water throughout the system and was continually impacted by high spring flows that often contained large amounts of sediment that washed out or plugged infrastructure. After Baca NWR was acquired by the USFWS, managers began inventorying and surveying existing ditches and water-control structures to determine water management capabilities and needs. Interim refuge management goals and objectives were stated in a Conceptual Management Plan developed in 2005, most of which focused actions on the evaluation, assessment, and monitoring of current biological attributes and infrastructure conditions (USFWS 2005).

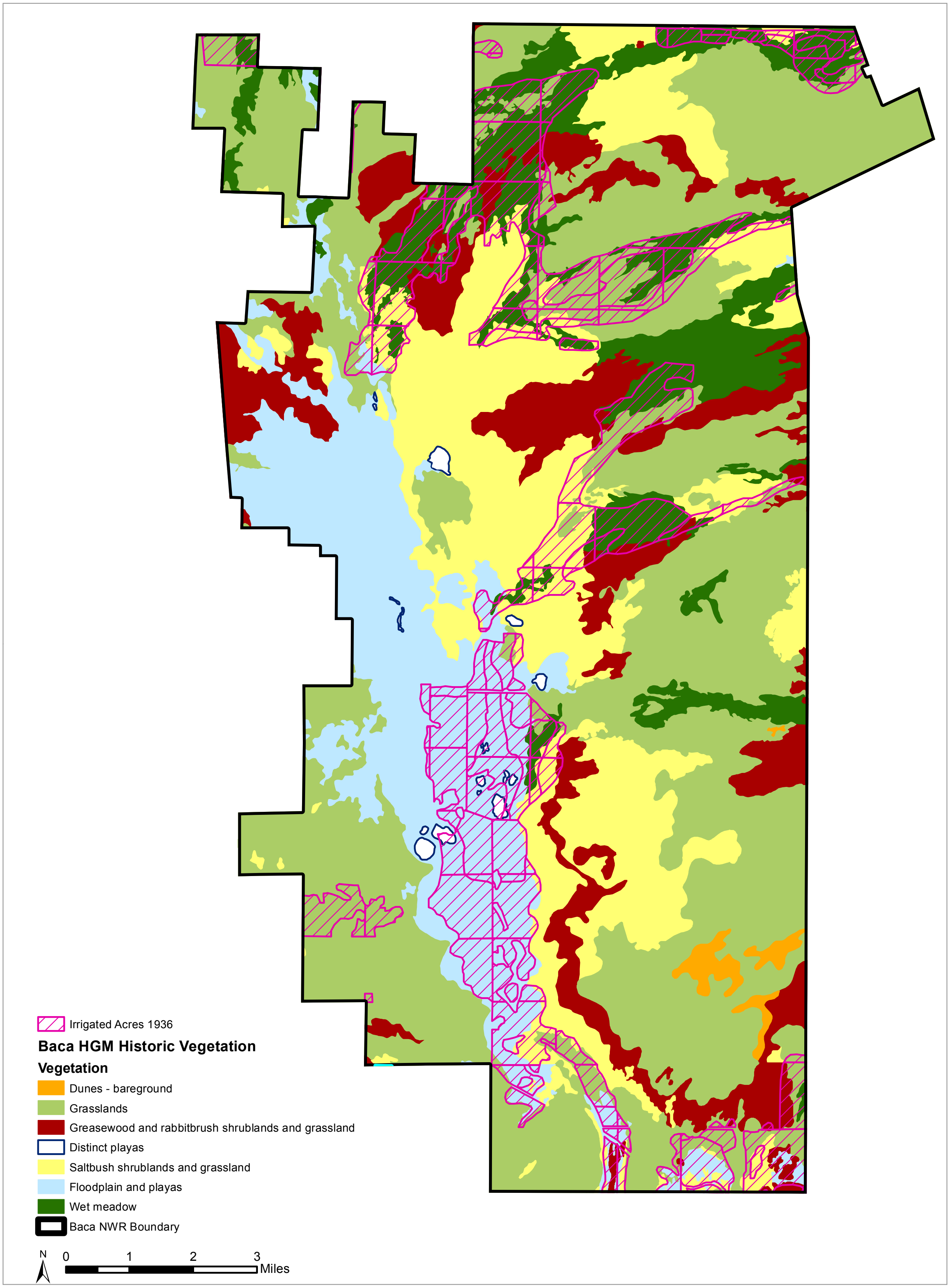

Figure 23. 1936 Irrigation of lands on Baca National Wildlife Refuge in relation to HGM potential historic vegetation communities.

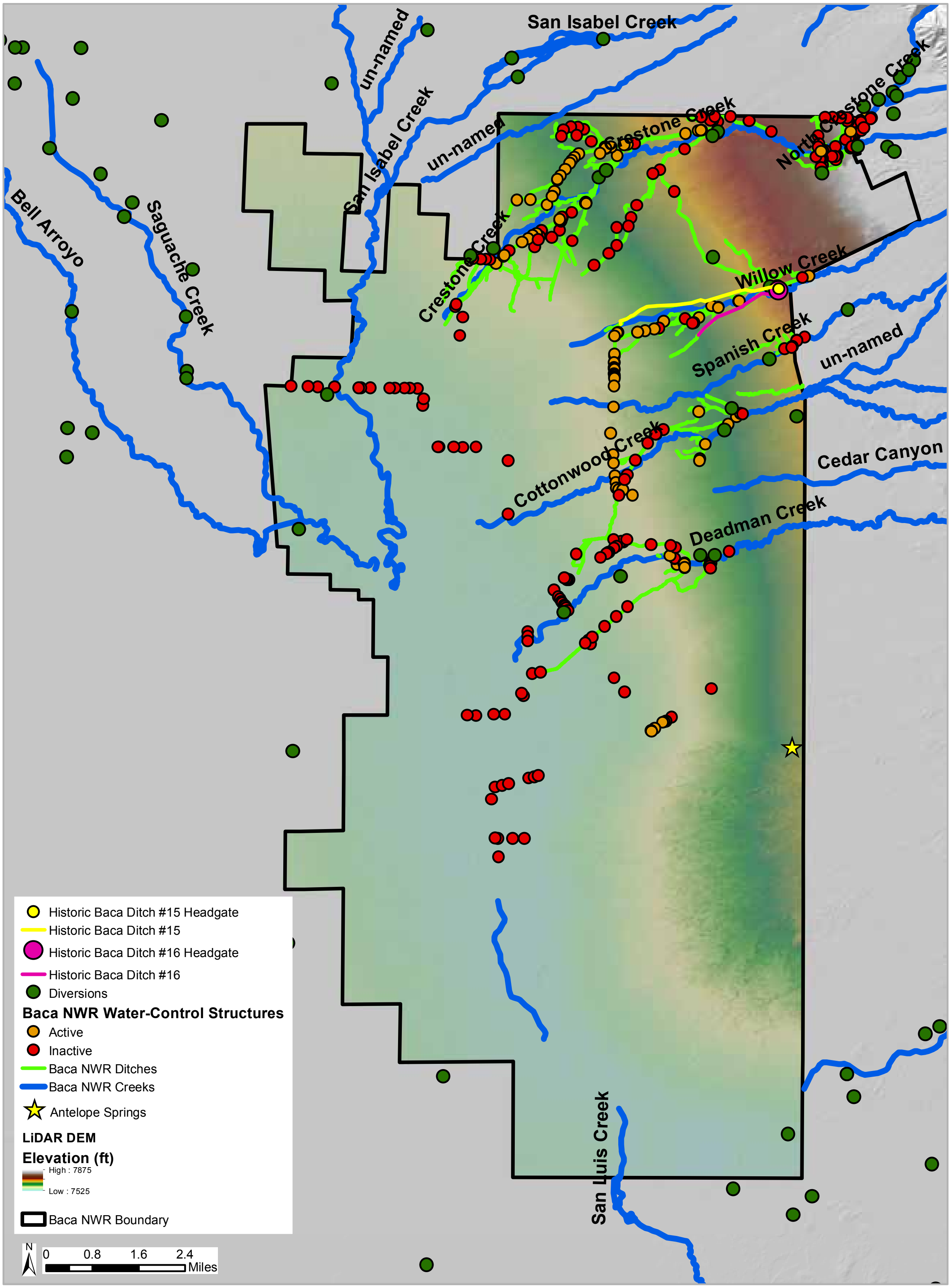

Figure 24. Location of water-control infrastructure in relation to elevation on Baca National Wildlife Refuge (water-control structure nomenclature taken from USFWS attribute table).

Approximately 150 miles of canals and ditches that move surface and groundwater to irrigated meadows or to the Closed Basin Canal have been identified on Baca NWR (Striffler 2013). Specific canals and ditches include the Closed Basin Canal and Baca Grant 4 Irrigation ditches (Fig. 24). The historic Baca Ditches and location of head gates on all creeks still exist and are used to irrigate meadows downstream. Baca NWR is the only water right holder on many of the creeks entering the refuge from the Sangre de Cristo Mountains. Diversion of this creek water is adjudicated for irrigation use. The WRIA (Striffler 2013) outlines the specific adjudications and locations of water resources on the Baca NWR. Historically, diversions were placed throughout the creek system based on annual water needs. Currently, the refuge is working with the Colorado Division of Water Resources (Division 3) to document precise locations of water diversions on each of the creeks. The refuge has irrigation rights associated with North and South Crestone, Willow, Spanish, Cottonwood, Deadman, and La Garita Creeks. Collectively, these rights total 619.88 cfs annually (Fig. 24; Striffler 2013). North Crestone Creek provides the largest decreed flow at about 163 cfs with Willow Creek providing the second largest decreed flow at 138 cfs. A draft database and GPS locations for the water delivery inventory has been completed on Baca NWR including locations of diversions, water-control structures/type/status, and the location of ditches (Figs. 24, 25). This database identifies 337 water-control structures; however, 225 are inactive (Fig. 24). Of the active structures, 45 are crossings, 53 are diversions, 4 are flumes, and 9 are plugs (Fig. 25). Ditches were rated as to condition with 57.6 miles documented at excellent or good and 34.7 miles documented as inoperable (Striffler 2013).

North Crestone Creek has the longest (but discontinuous) record of discharge (1936-present) among the creeks that originate in the Sangre de Cristo Mountains. This creek discharge averaged 8,700 acre-feet/yr with a high of 21,745 in 1941 to a low of 1,621 acre-feet/yr in 2002 (Striffler 2013, Fig. 17a). Over time there has been a slight decrease in the overall annual stream discharge of this creek, which closely corresponds to decreases in precipitation measured in Crestone, Colorado. Other creeks such as Cottonwood, Willow, and Spanish have shown a slight increase in flow from 1999 to 2010 although variation among years is apparent in all of the creeks (Fig. 17b).

Currently, Baca NWR has 7 active wells decreed to produce over 50 gallons/minute (gpm). Two wells require maintenance and meter certification before being used (Striffler 2013). RGDSS well inventories documented for the SLV characterized wells as decreed, small, or other (Fig. 26). A total of 134 wells are owned or used by the refuge with 80 in the confined aquifer and 24 in the unconfined aquifer. An additional 30 wells have not been identified as to aquifer location. Most of the wells have been listed as “inactive,” partly due to their age and poor condition. Many of the small wells on the refuge are small confined aquifer (artesian) wells and have been used as stock wells and may or may not be flowing at the present time due to the declining artesian pressure. Baca NWR has a lease agreement with the Baca Grande Water and Sanitation District to provide up to 4,000 acre-feet of water to meet the needs of the Baca Grande Subdivision, however, the amount used on an annual basis is much less (Striffler 2013). The USFWS is responsible for maintenance of water rights associated with the lease agreement including groundwater resources, augmentation, and any change of case court filings. If the USFWS could sell the Baca Grande water rights it would relieve local and regional staff of this burden and may be a reasonable avenue to pursue (Striffler 2013).

Water quality of the creeks flowing from the Sangre de Cristo Mountains, and surface water in general, on Baca NWR has been good over time with little change since 1967 (Striffler 2013) due partly to the location of the refuge in near proximity to the headwaters with little upstream agricultural activities. While surface water at Baca NWR has been of good quality, groundwater on portions of the refuge may have quality concerns. Groundwater may contain high levels of iron bacteria and manganese deposits that could contribute to bio-fouling in wells and pumps that can reduce productivity (Striffler 2013). A study by Powell (1958) found that groundwater located within the Closed Basin Project had high levels of sodium concentrations that would not be suitable for irrigation unless diluted. Some water quality issues may arise resulting from the Baca Grande Water and Sanitation District due to effluent releases and the infrastructure associated with the current wastewater treatment facility. At this

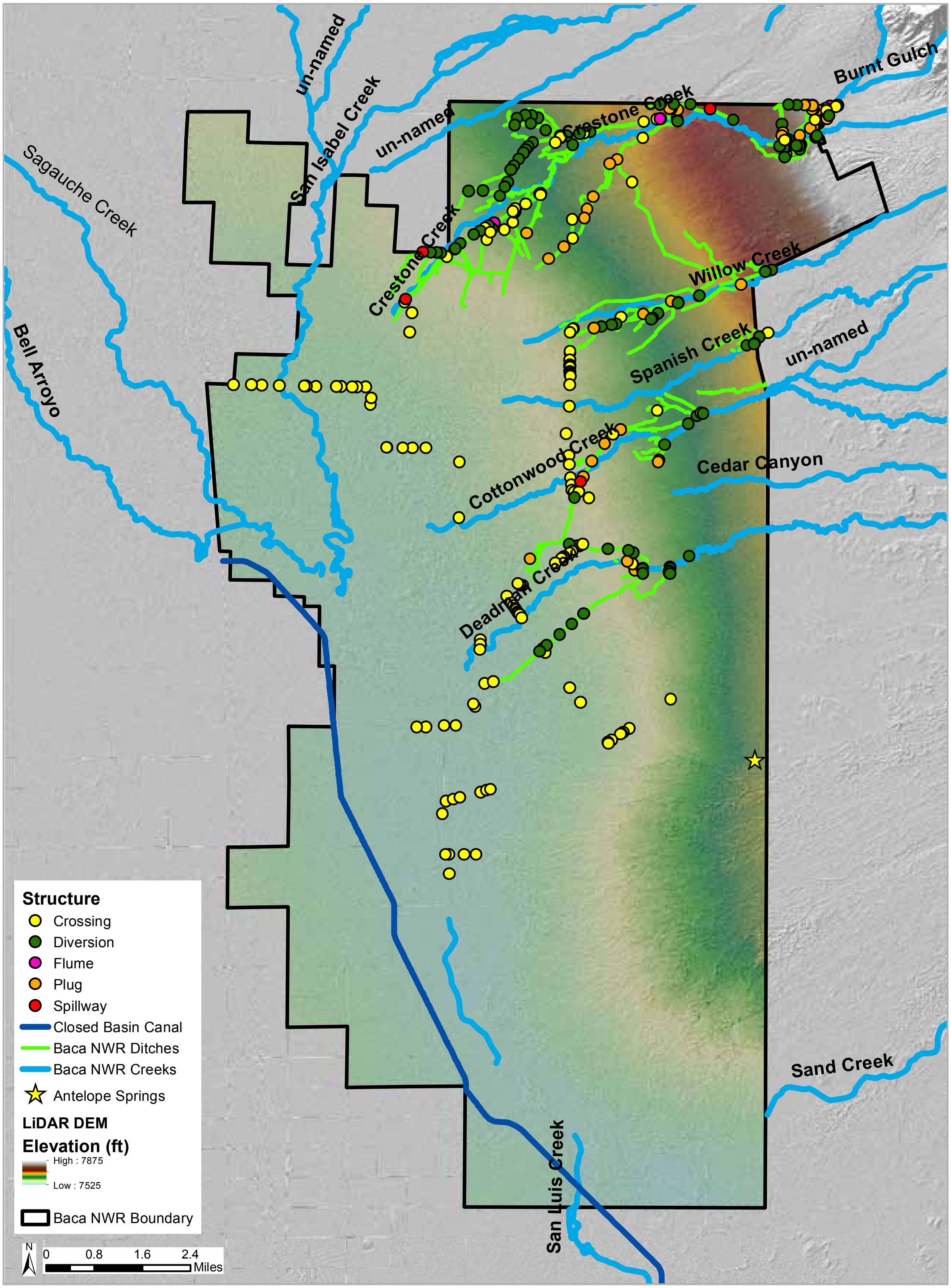

Figure 25. Location of water-control infrastructure in relation to elevation on Baca National Wildlife Refuge by type of structure (water-control structure nomenclature taken from USFWS attribute table).

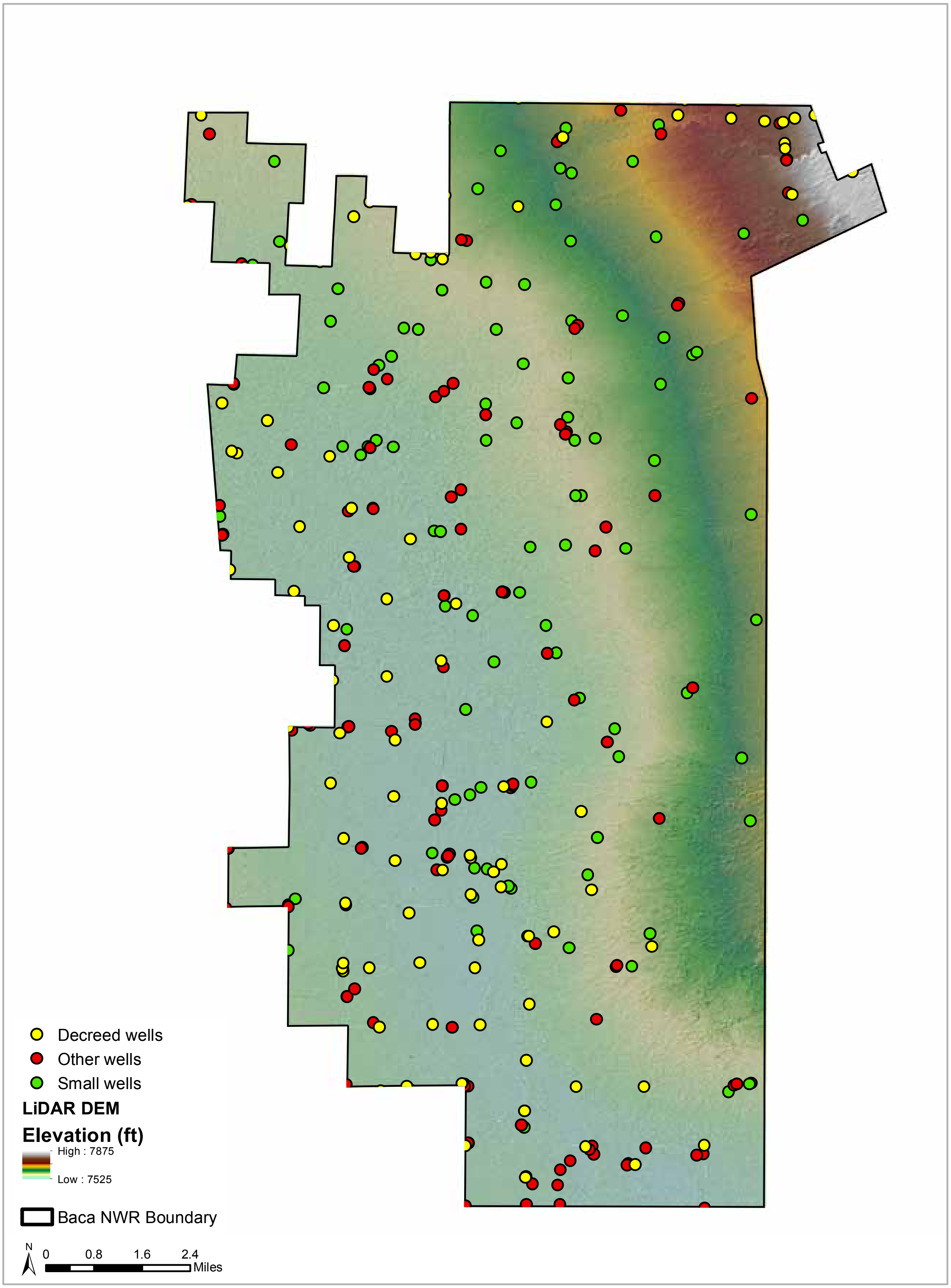

Figure 26. Location of well types on Baca National Wildlife Refuge.

time recent sampling has indicated that there are no water quality issues resulting from this source. Other contaminants that the USFWS may need to monitor and minimize may potentially arise from further energy development on the Baca NWR (Striffler 2013). A Contaminant Assessment Process Report (CAP) was completed in 2009 for the San Luis Valley Refuge Complex with specifics related to the Baca NWR contained in Appendix C. The CAP report indicated that the entire refuge complex was "relatively uncontaminated."

Currently, Baca NWR does not have any surface water rights associated with the Closed Basin Project, however, the Project mitigates for groundwater losses through refuge use of a well on the White Ranch (Striffler 2013). Many unconfined aquifer levels within the Closed Basin Project boundary have been declining and the amount of water extracted by pumping has exceeded the amount that is recharged (Rio Grande Water Conservation District 2012). Declines in artesian pressure in many wells were observed in the late-1980s; many now are dry (Eddie Clayton personal communication). Surface water sheetflow across Baca NWR also has been altered with the establishment of BOR roads built to the wells associated with the Closed Basin Project. Many of these roads bisect playa wetland basins and alluvial fans and alter natural water flow patterns. Currently, groundwater pumping to supply the CBC and other local agricultural activities has contributed to the general lowering of the regional water table, which has resulted in decreased water flow in creeks that historically flowed through the refuge, reduced or eliminated flow from springs, and impacted the regional hydrology and ecology of wetlands on Baca NWR and adjacent lands (Cooper and Severn 1992).

Parts of the Baca NWR area historically were described as having "gassy" water according to accounts from Gunnison's Expedition (Unknown 1970), Seibenthal (1910) and articles written in the San Luis Valley Historian (Reddin 1979). Camps established on lands now in Baca NWR in the 1920s were known to have water tinged with gas, and laborers often required several days to become accustomed to drinking this water (Reddin 1979). A rancher named J.M. Crow owned an artesian well in 1949 that produced copious amounts of gas, which powered the appliances in his house, fireplaces, and water heaters (Denver Post, April 15, 1949). Siebenthal (1910) noted that the gas occurred in something like a trough below the natural sump area in the Closed Basin. Currently, Lexam Exploration, Inc. (Lexam) owns most of the subsurface mineral rights including oil and gas on Baca NWR. Over time, different entities have drilled exploratory wells in the area, with a wide range of results. Surveys indicate that there may be viable natural gas reserves in the Baca Graben (USFWS 2011). An initial EA was completed in 2008 and a second EA was completed in 2011 (USFWS 2011) as part of a settlement from a lawsuit brought by the San Luis Valley Ecosystem Council and others against the USFWS. The preferred alternative of the 2011 EA established numerous terms and conditions designed to protect the natural and cultural resources of the refuge during the drilling of the two proposed exploratory wells. However, it still allows Lexam to drill the two wells, Baca#5 near Willow Creek and Baca#7 near Spanish Creek, on the refuge.

REFUGE WATER AND HABITAT MANAGEMENT AND ECOSYSTEM CHANGES

Annual water management on the Baca NWR generally has been consistent over the past century and a quarter with the adjudicated water rights allowing for the irrigation of playa and wet meadow areas, both prior to and after refuge establishment (Murphy 2009, Dieni 2010, Ron Garcia personal communication). Some changes have occurred in the past 20 years resulting from decreased water flow through the creeks. The following paragraph describes the typical water diversion and management efforts on the refuge designed to provide irrigated wet meadows historically for hay production and grazing (Murphy 2009, Dieni 2010a,b; Eddie Clayton personal communication).

Overall available water resources are divided through the use of water-control structures to provide equal distribution of surface water sheetflow across the largest area possible on Baca NWR. The flow of ephemeral creeks coming out of the Sangre de Cristo Mountains can vary greatly on a daily basis and water-control structures can be easily washed out if the flow exceeds the capacity of the structure or if structure manipulations cannot be changed quickly enough to prevent overflowing events. Most natural creek flows are diverted primarily to provide water for meadow habitats, which results in water from the Sangre de Cristo Mountains rarely reaching the playa lakes (USFWS 2005). Many of the playa lakes also historically were supported through natural rises in groundwater which currently no longer occur due to declines in the water table. Water from these lakes historically overflowed south through the broad San Luis Creek drainage toward the San Luis Lakes State Wildlife Area and into two large playa lakes. This water "flow-through" rarely if ever occurs now. Irrigation of wet meadows begins in May and extends through mid-July (Murphy 2009; Dieni 2010a,b). Most recently playa lakes have received water from diversions of Crestone, Willow, Cottonwood, and Deadman creeks and from an unconfined aquifer well (pumped) on the White Ranch unit of the refuge.

As early as 1910, Siebenthal (1910) noted that lands in the SLV that were "broken out" for production were left fallow and had begun to revert back to upland shrub, namely greasewood. Management strategies, development of infrastructure, and the alteration of topographic features have changed the vegetative distribution and composition of shrublands, wet meadows, grasslands, and riparian corridors throughout the refuge. Specifically shrubland habitat, grasslands, and potentially riparian corridors have decreased in and around areas that have been used for decades for hay and pasture, and have shifted communities towards Baltic rush, sedges, introduced grass cultivars, and invasive species. Current vegetation maps for Baca NWR indicate changes in community distribution over time including development of "transition" mixed shrub-grassland in large areas of the eastern portion of the refuge where grasslands formerly historically existed (see comparison in Figs. 21, 23, 27, and 28). Greasewood-dominated shrublands also have increased dramatically around the playa areas and have replaced former extensive grasslands in these areas.

Inter-dunal swale areas currently coincide with creek channels (Fig. 28), however the potential historical distribution of vegetation model map (Fig. 21) includes these sites in shrub and grassland habitat because of site-specific soils, topography, and hydrologic regime. The National Wetland Inventory (NWI) maps developed in the late-1980s characterize a majority of wetlands located on the refuge as freshwater emergent with a few freshwater ponds, lakes, and another type classified as "other" (Fig. 29). Most of the eastern portion of the refuge, away from creek drainages on the alluvial fans, currently contains upland type habitat. Upland areas correspond to the Sandsheet Rabbitbrush Shrubland and Steppe Alliances map group from the 2006 vegetation mapping project (Fig. 28). The 2006 map indicates that rabbitbrush dominates the alluvial fans on the east side of the refuge; these areas historically were probably dominated by Artemisia species based on historical evidence provided by the GLO surveys and supporting soil series with potentially a secondary rabbitbrush shrub component (Figs. 4, 5, 13, 21, 28). Greasewood dominated areas on the 2006 map comprise approximately 24,600 acres (USFWS 2005). Intermittent wetland areas mapped as Playa Alliances (Figs. 21, 29) were scattered throughout the floodplain of San Luis Creek on BBG association soils. Approximately 55 playa lakes currently occur throughout this soil association. The largest, Weisman Lake, covers 61 surface acres near the mouth of Cottonwood Creek (Fig. 16, Striffler 2013).

GLO surveys and historical accounts indicate that eastern portions of the alluvial fans of what is now Baca NWR historically were covered by salt desert shrub and by large expanses of grassland (Fig. 5, 20; Unknown 1970). As previously mentioned, the exact historical composition of upland shrublands is uncertain, but current shrublands have increased amounts of greasewood and/or rabbitbrush and former grasslands now have a higher composition of shrubs, especially greasewood (noted as transition habitat in Fig. 28) or have been converted to different types of wetlands. A variety of factors including haying, grazing, and changes in hydrologic regime apparently have caused these habitat changes through increased soil temperature and salinity to name a few. Changes in soil temperature and salinity stress individual plant species differently throughout the growing and dormant seasons depending upon their physiology and growth characteristics (e.g., see Sayre 2001).

Livestock grazing on Baca NWR lands historically occurred by moving stock to large (i.e. up to 5,000 acres) fenced upland pastures during the growing season and then moving them to more concentrated areas along creeks and wet meadows

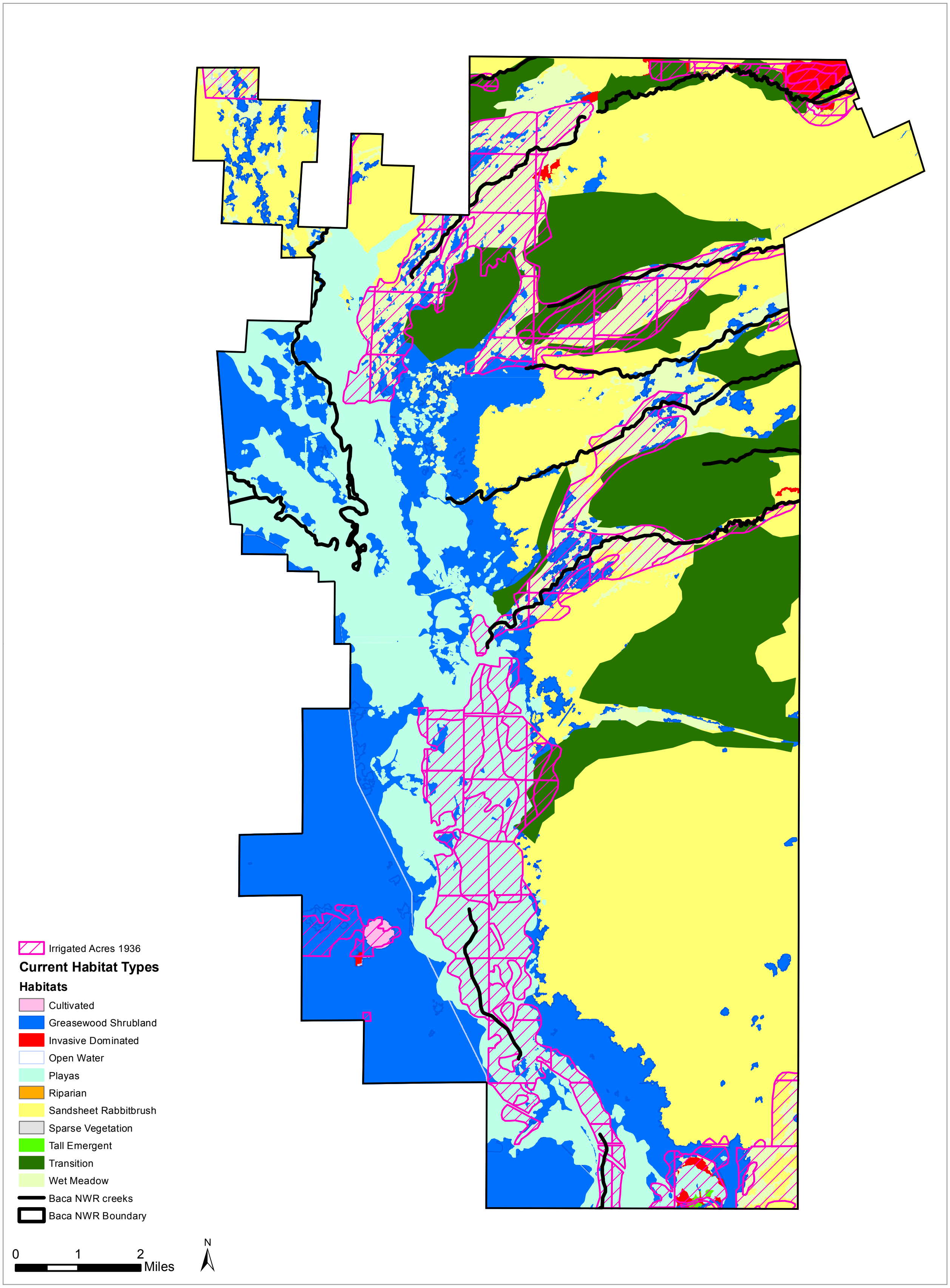

Figure 27. 1936 Irrigation of lands on Baca NWR in relation to current habitat types.

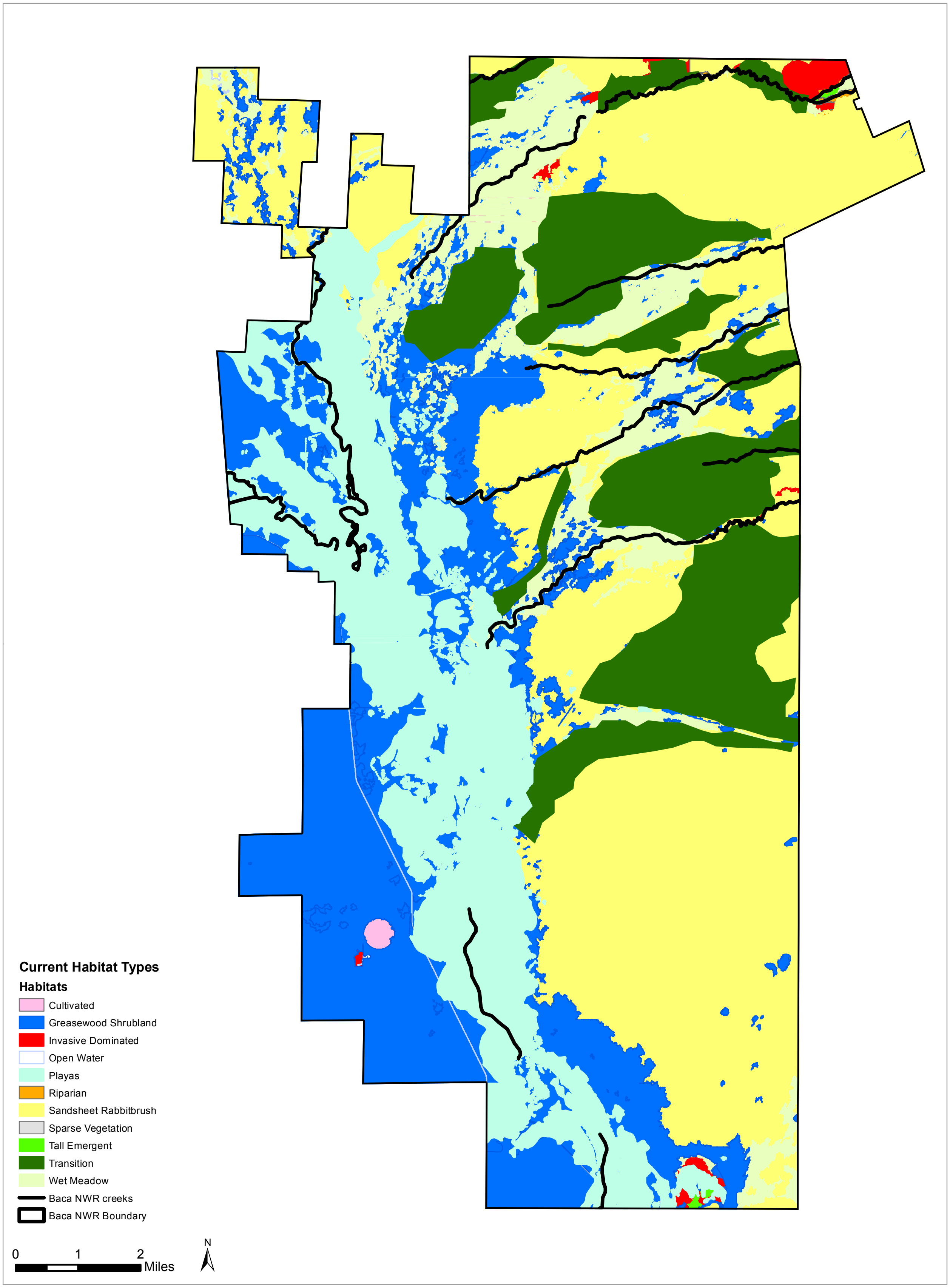

Figure 28. Current general vegetation type coverage on Baca National Wildlife Refuge (furnished by USFWS staff).

during the fall and winter seasons. Wet meadows adjacent to stream courses on Baca NWR were especially used for haying and grazing because flood irrigation was/is possible in these locations. Historically, the town of Moffat, Colorado (Fig. 1) was an important point for gathering livestock to be transported via railroad to Denver (Oliver 1985). Historic cattle grazing management at Baca NWR used stocking rates that typically removed about 50% of the vegetation left after wet meadows were hayed (refuge staff personal communication, Murphy 2009). Elk also graze these areas heavily (Murphy 2009). If herbaceous plants become overgrazed in the Baca NWR region, shrubs like greasewood increase in cover and density throughout the historic grassland locations (SCS 1981). Cultivars such as alsike clover (*Trifolium hybridum*) have become established in wet meadow communities and represent the most widespread introduced forb species on the refuge (Dieni 2010a,b). Invasive plant species also occur in wet meadows and playas, and from 2006 to 2010 sheep grazing was prescribed on the northern half of the refuge to control knapweed (Fig. 30).

Historically, mule deer, pronghorn, elk, and bison were present on Baca NWR and adjacent areas. By the 1840s pronghorn and bison were extirpated (Schoenecker et al. 2005) and ranching interrupted use patterns of native ungulates. Since that time the development of water resources, urbanization, conversion of upland vegetation communities, introduction of crops, and hunting pressure have been factors in concentrating elk on those public lands that do not allow elk hunting (USFWS 2005; Schoenecker et al. 2005; Schoenecker et al. 2004). Currently about 1,500 to 3,000 elk use Baca NWR during the winter months and about 1,000 elk can be present throughout the summer (Keigley et al. 2009). Elk began utilizing Baca NWR more extensively in the late-1980s, and significant decline of the willow along creek corridors is thought to have occurred around 1999 when elk browsing went from light to heavy (Keigley et al 2009). Exclosures placed in 2006 around some existing willow stands indicate that browsing by elk of new young plants, antler thrashing, and cattle rubbing have been the main causes of decline; these effects have been exacerbated by lower water tables in

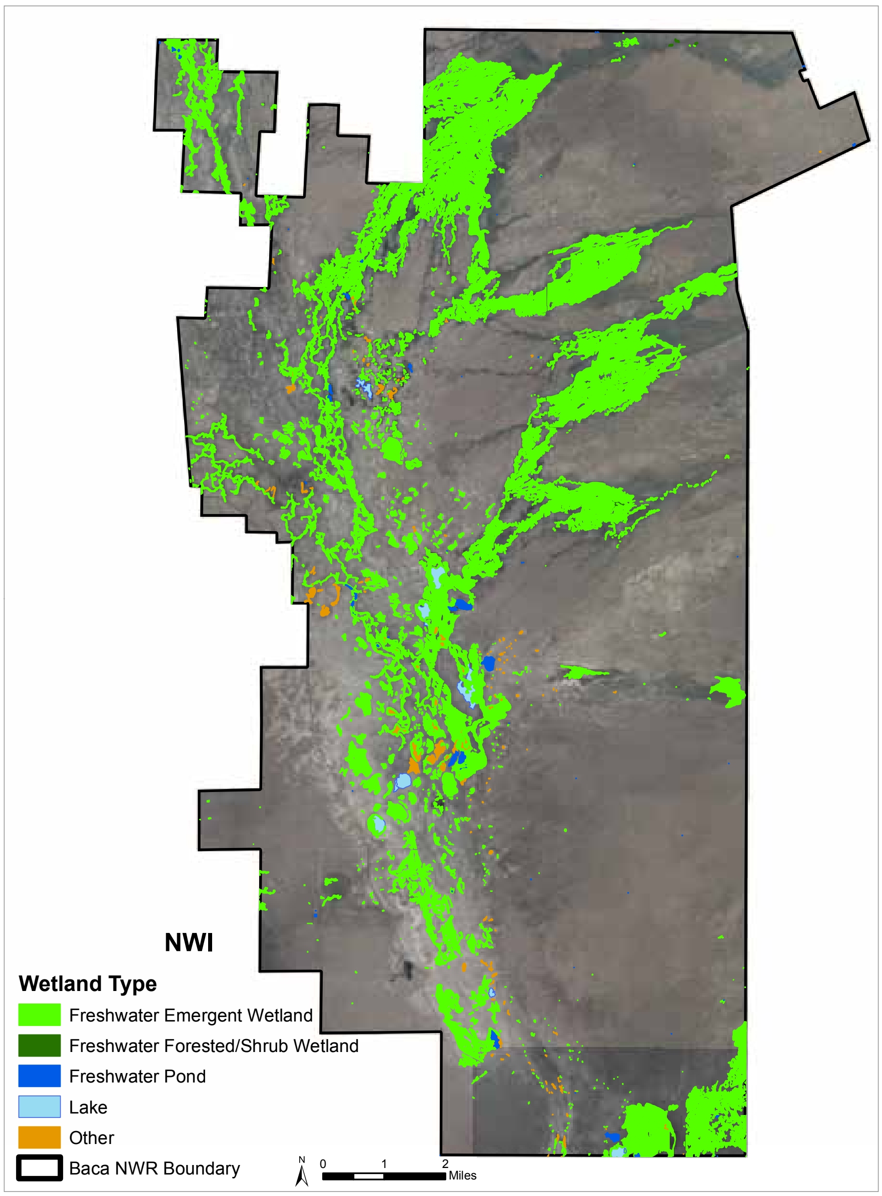

Figure 29. National Wetland Inventory wetland categories on Baca National Wildlife Refuge.

recent years (Keigley et al. 2009; Schoenecker et al. 2005). Browse of young willow and cottonwoods is currently 100%; regeneration of this community could occur if approximately 42% of new willow and 18% of new cottonwoods remained un-browsed (Keigley et al. 2009). Over-browsed areas by ungulates also could alter the Nitrogen (N) cycles by reducing above ground biomass, litter, transferring N to other vegetation associations, and decreasing overall N mineralization in the soil in short willow stands (Schoenecker et al. 2004). Depending on the plant species, browsing may positively or negatively impact the vegetation community. For example, elk may seek out willow stands for forage and bed down in shrub/grassland areas, transferring the N out of the willow riparian area and releasing it through urine and feces in other areas (Schoenecker et al. 2004).

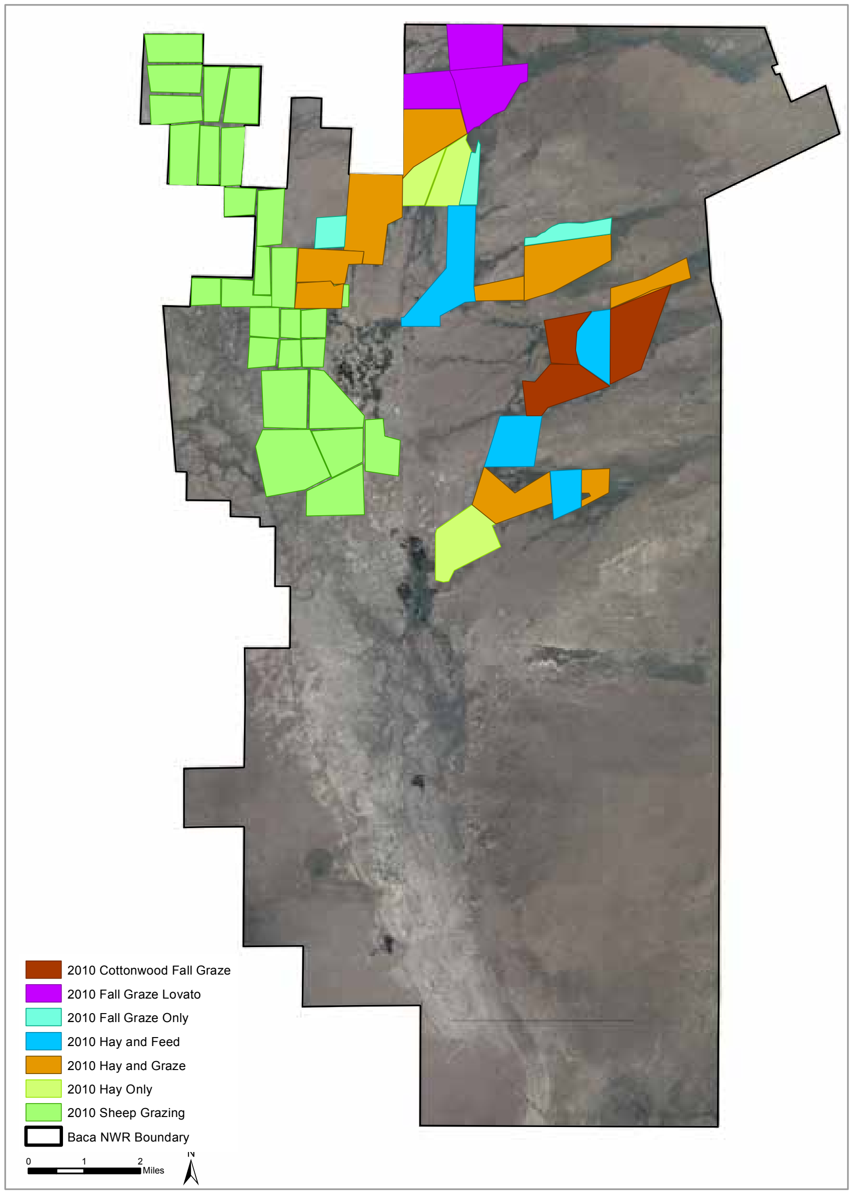

Figure 30. Hayed, grazed, and combined hayed and grazed areas on Baca National Wildlife Refuge in 2010.

The lack of woody plant regeneration in some riparian areas also may be due to declines in mature willows producing seed, as most new growth appears to occur from root propagation (Keigley et al. 2009). Deadman Creek historically contained some willow-dominated riparian areas (Unknown 1970) but these willow stands now are almost completely gone because of overgrazing and haying of wet meadows along the creeks. Other factors which may be contributing to the decline include long periods of drought which have contributed to a persistently lower water table and the redistribution and expansion of dunes in some areas where willow historically grew (Schoenecker et al. 2005). Head-cut erosion, including areas on Crestone Creek near the northeastern refuge boundary and along Sand Creek (see Wurster and Cooper 2000), promotes a lower water table thereby reducing bank storage and available resources for maintaining willow growth and regeneration (Zeedyk and Clothier 2009). Root development of cottonwood is related to the depth of the underlying water table (Scott et al. 1999) and severe and rapid reductions in water table levels can cause extensive mortality of cottonwood, especially young saplings that have not developed root systems at various depths to offset large fluctuations (Shafroth et al. 2000, Anderson 2005). Drought conditions creating low flows in creeks along with well developments on and off of the refuge such as groundwater wells leased to the Baca Grande Water and Sanitation District, have undoubtedly contributed to decreases in local water tables and may have increased mortality of riparian vegetation. Annually consistent grazing that occurred over the past century, especially in newly established cottonwood and willow communities, also impacts the diversity and complexity of riparian woodland stands along with the wildlife communities that depend on them (Shafroth et al. 2000). Haying activities, which occurred prior to 2004 on Baca NWR, continuously cut new willow growth along with all other plant species and have been a factor in the re-expansion of these species into adjacent hay meadows (Keigley et al. 2009).

It is generally believed that invasive weeds have been kept from dominating wet meadow habitats on Baca NWR because of past intensive livestock grazing/haying practices (refuge staff personal communication). Nonetheless, invasive weeds that are widely distributed on the refuge include tall whitetop (*Lepidium latifolium*), Canada thistle (*Cirsium arvense*), and Russian knapweed (*Acroptilon repens*); the largest concentrations seem to occur along creek and ditch corridors (USFWS 2005). Control of invasive species has been conducted annually at various levels with chemical and physical treatments (USFWS 2005). In the recent past, mowing of upland shrub habitat has been undertaken to stimulate new, native plant growth and reduce residual vegetation (Hanson personal communication). Some information indicates that disturbance of rabbitbrush shrublands increases the occurrence of weed species until the shrubs show some re-growth (Scheinost et al. 2010). Other invasive plant species that have been observed on the refuge include salt cedar (*Tamarix ramossissima*), giant reed (*Phragmites* spp.), quackgrass (*Elymus repens*), and timothy (*Phleum pratense*) (USFWS 2005).

CHANGES IN ANIMAL POPULATIONS

The historic complex of vegetation communities on Baca NWR provided resources for populations of many animal species. Over time, water resources and various management strategies altered vegetation community types and impacted wildlife species diversity and distribution. For example, the entire Saguache Creek corridor, including at least a portion on Baca NWR, historically was an important area for spring migrant waterbirds (Hopper et al. 1975). Diminishing groundwater and redistribution of surface water from this and other local creeks gradually changed the availability and timing of resources for migrating waterbirds throughout the entire Closed Basin region (Hopper et al. 1975). Haying and grazing also has affected bird use of Baca NWR. A 2008 study indicated that hayed/grazed versus unmanaged areas offered habitat for different breeding bird species dependent on their habitat needs (descriptions used as per Murphy 2009). Hayed/grazed areas that were routinely dry in May but were wet in June were used by Wilson's snipe (*Gallinago gallinago*), Wilson's phalarope (*Phalaropus tricolor*), red-winged blackbirds (*Agelaius phoeniceus*), and brown-headed cowbirds (*Molothrus ater*). Unmanaged areas typically were occupied by horned lark (*Eremophila alpestris*), western meadowlark (*Sturnella neglecta*), Brewer's sparrow (*Spizella breweri*), and vesper sparrow (*Pooecetes gramineus*), which sought out taller and denser meadows or shrub type habitats (Murphy 2009). Savannah sparrow was the overall dominant species observed during the breeding season in 2009 (Dieni 2010a,b). This species seems to prefer unmanaged or idle meadows but also will nest in hayed/grazed areas. During the breeding bird studies conducted by Murphy (2009) and Dieni (2010a,b) very few wetland-dependent birds were observed in sampled wet meadow sites. Information obtained in 2008 and 2009 represent a dry and wet year, respectively, leading Dieni to speculate that many birds probably are not using wet meadows on the Baca NWR for breeding. In 2009, only about one percent of the breeding bird species identified at Baca NWR were waterfowl, with mallards being the most common (Dieni 2010a,b). In the post-breeding and fall migration period, savannah sparrows and western meadowlarks were documented as being the most dominant species observed with the savannah sparrow being prone to unmanaged or idle meadows (Dieni 2010b). Waterfowl, waterbirds, and shorebirds were observed during a cursory inventory of two playa wetlands during this same post-breeding time period. As part of a sandhill crane (Grus canadensis) study, approximately 75 cranes were observed using some areas on the Baca Refuge in fall 2002 (Baca NWR unpublished data).

Other species that may have or are currently relying on grasslands and shrublands on the Baca NWR include the short-eared owl (*Asio flammeus*) and burrowing owl. These species were documented during a survey completed in Antelope Springs which lies on the eastern boundary of the refuge (Fig. 3, Colorado Natural Heritage Report 2012). Short-eared owls were observed hunting in the saltgrass meadows and shrublands, and it was proposed that the owls may be nesting near Weisman Lake on the refuge. Burrowing owls were observed utilizing burrows of the northern pocket gopher found at Antelope Springs. This species may utilize other areas on the refuge for forage. Saltgrass meadows associated with areas like the springs or those found on the White Ranch portion of the refuge also may provide important resources for the San Luis sandhills skipper (*Polites subleti ministigma*) which is a globally rare butterfly in the SLV (Colorado Natural Heritage Report 2012; Rondeau and Sanderson 1998). Rabbitbrush and greasewood shrublands associated with Antelope Springs, and other areas on the refuge, also may provide habitat for a variety of insects and invertebrates which in turn support many songbirds and small mammals (Tilley et al. 2005). The slender spider flower may become adapted to disturbances such as those created by the northern pocket gopher observed during the survey at Antelope Springs (Colorado Natural Heritage Program 2012).

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OPTIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

The establishment of Baca NWR and other contiguous federal and state lands has protected one of the largest, relatively intact, native landscape tracts in the SLV. The large size and single long-term ownership of much of the land now in Baca NWR largely prevented landscape fragmentation and conversion to intensive agriculture. The unique ecological character of Baca NWR should continue to be protected and many opportunities exist to restore basic physical and biotic attributes, function, and values of the tract.

The primary ecosystem changes in the Baca NWR region that should be addressed for future restoration and management goals, are: 1) alterations to distribution, chronology, and abundance of surface water entering the refuge; 2) diminished groundwater levels due to well pumping including the Closed Basin Project; 3) conversion of upland shrub and grasslands to artificially managed and maintained wet meadows or greasewood habitat areas that have higher salinities; and 4) alteration to local topography.

A major challenge for future management of Baca NWR will be to determine how to restore and emulate natural water regimes and water flow pathways on the refuge to restore and provide critical habitats and communities for wildlife within constraints of water rights (such as use of water for historical grazing and hay production), Closed Basin Project authorizing legislation, refuge establishment purposes, and USFWS policies. Since the USFWS has had management authority of Baca NWR, efforts have been targeted at gaining baseline information on historical land use practices such as haying and grazing of cattle. These efforts have prompted staff to begin upgrading some of the infrastructure while providing resources for a variety of wildlife species. Continuation of past management practices and use or modification of present water infrastructure may or may not be consistent with potential future objectives that seek to restore and emulate natural distribution, abundance, and processes of endemic communities. If additional restoration of native communities is desired on Baca NWR, then future management issues that affect timing, distribution, and movement of water on the refuge must consider how, and if, they are contributing to desired objectives of restoring native communities and their processes on the refuge. Additionally, future management on Baca should be designed at a landscape level with the cooperative effort of other adjacent large public and private land conservation areas. Cooperative efforts are desirable and enable a landscape-level look at the larger system as a whole in order to restore, for example, entire stream courses in relation to bed level and floodplain access.

GENERAL RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

This HGM evaluation seeks to identify restoration and management options that could protect, restore, and sustain natural ecosystem processes, functions, and values at Baca NWR. Certain options may be currently constrained by legal, political, or social factors (such as refuge water rights), however, the purpose of this report is to discuss all potential options because future legislation, administrative actions, and USFWS policy may change, especially if the changes are deemed important for more holistic sustainable management and protection.

This HGM evaluation does not address where, or if, the many sometimes competing uses of the refuge can be accommodated, but rather it provides information to support The National Wildlife Refuge System Improvement Act of 1997, which seeks to ensure that the biological integrity, diversity, and environmental health of the (eco)system (in which a refuge sets) are maintained (USFWS 1999, Meretsky et al. 2006, Paveglio and Taylor 2010). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation, 2) assessment of each refuge's importance across landscape scales, and 3) recognition that restoration of historical processes is critical to achieve goals (Mertetsky et al. 2006). Most of the CCP's completed for NWR's to date, and the Conceptual Management Plan prepared for Baca NWR in 2005 (USFWS 2005) have highlighted ecological restoration as an objective. Generally, historical conditions (those prior to substantial human related changes to the landscape) are considered the benchmark condition to guide restoration efforts (USFWS 2001, Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historical conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s) (USFWS 2001).

Given the above USFWS policies and mandates for management of NWR's, the HGM approach used in this study can assist decisions about future management of Baca NWR, at least where some restoration of historical communities and ecological processes is desired. The HGM approach objectively seeks to understand: 1) how this ecosystem was created, 2) the fundamental physical and biological processes that historically "drove" and "sustained" the structure and functions of the system and its communities, and 3) what changes have occurred that have caused degradations and that might be reversed and restored to historic and functional conditions within a "new desired" environment. Baca NWR lies adjacent to other large public lands that, while having different objectives, also have somewhat similar issues regarding changes in hydrological flow, conversion of habitats (see e.g., Wurster and Cooper 2000), invasive weeds, and other management concerns. Adoption of management strategies to restore functional ecosystems on Baca NWR may be a catalyst to develop cooperative restoration efforts among other agencies to implement management that complements the various land holdings and leads to a more cohesive landscape conservation vision and plan.

HGM evaluations are not species-based, but rather seek to identify options to restore and maintain system-based processes and native plant communities that ultimately will help support local and regional populations of endemic species, both plant and animal, and other ecosystem functions, values, and services. The development of specific management strategies for Baca NWR should include understanding of the historic context of the Baca NWR area relative to what communities naturally occurred there, the seasonal and interannual dynamics and thus availability of community resources, and when and where (or if) species of concern actually were present on the tract and what resources they used. Discussion of restoration and management options in this HGM evaluation are intended to advance the goal of maintaining the ecosystem itself, with the assumption that if the integrity of the system is maintained and/or restored, biodiversity for all species and key resources for species of concern and will be available. This approach is consistent with recent recommendations to manage the NWR system to improve the ecological integrity and biodiversity of landscapes in which they sit (Fischman and Adamcik 2011). Obviously, some systems are so highly disrupted that natural processes and communities/resources cannot be completely restored.

Fortunately, much of the physical integrity and presence of native communities and associated resources remain intact on Baca NWR. This report helps identify changes to the Baca NWR ecosystem that have compromised or somewhat altered certain important ecological processes (e.g. amount and distribution of surface- and groundwater). Clearly, some conservation and management actions that potentially can help restore or improve these altered ecological processes will require efforts beyond the boundaries of Baca NWR and will require cooperative efforts by many entities (for example, government and state agencies, private conservation organizations, regional communities, and private landowners). One such example of a recent cooperative regional conservation effort is the State of Colorado initiating proposals for "Groundwater Rules and Regulations" that are designed to recover groundwater to sustainable levels, which ultimately should help improve water resources on Baca NWR.

Based on the HGM context of information obtained and analyzed in this study, we suggest that future management of Baca NWR should consider efforts to:

1. Restore natural water flow pathways and creek/floodplain processes where possible in Crestone, Cottonwood, Willow, Spanish, and Deadman Creeks.
2. Restore natural hydrological regimes in playa wetland systems throughout the historic San Luis Creek drainage.
3. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes where possible.
4. Manage herbivory in riparian areas, wet meadows, grasslands, and shrublands to emulate natural processes and conditions.

The following general recommendations are suggested to meet these suggested ecosystem restoration and management goals for Baca NWR.

1. Restore and promote natural water flow pathways and processes where possible in Crestone, Cottonwood, Willow, Spanish, and Deadman Creeks.

Restoration of natural communities to promote availability of resources for wildlife at Baca NWR will require basic changes in how water flow patterns and processes occur in the creeks that flow onto the refuge, while recognizing and working within legal constraints including the refuge's authorizing legislation. Collectively, topography, water-control infrastructure, and refuge water management plans must be evaluated further to identify possible beneficial changes. First, the topography and natural water flow and drainage patterns of Baca NWR have been altered from their historic condition. Roads were built across Baca as early as the late-1800s (e.g., GLO maps; Reddin 1980); many creeks flowing onto the refuge were channelized and developed for water diversion; and multiple ditches, drains, and canals were constructed. These developments dissected the floodplain and prevented water from flowing through certain natural topographic features. Collectively, the surface and groundwater developments on and off the refuge have altered native vegetation communities from their native state. The diversion of surface water from creek channels to large areas on the alluvial fan, especially areas in the northeastern part of the refuge that historically were grasslands and shrublands (Fig. 21), created large expanses of "transition" habitat areas (Fig. 28) and expanded some wet meadow areas. Ditches currently divert water perpendicular to the natural flow of water, specifically between Crestone and Willow Creeks, Spanish and Cottonwood Creeks, and Cottonwood and Deadman Creeks (Fig. 24). Currently, Saguache Creek no longer empties into San Luis Creek on Baca NWR because of upstream diversions and diminished groundwater levels from pumping throughout the SLV. Diminished or nonexistent inputs to San Luis Creek from Saguache Creek on the west and from the Sangre de Cristo creeks on the north and east have drastically changed how the Upper Sump functions. Much of the San Luis Creek drainage area is bisected by BOR roads and by pipelines that move groundwater from Closed Basin salvage wells to the CBC (Figs. 24, 31, 32).

Fortunately, most natural drainage patterns still exist on Baca (as evidenced by recent LiDAR imagery), although some may be difficult to discern from artificial ones after a century of consistent flood irrigation. Drainages identified on 1941 aerial photos (Fig. 6) and recent LiDAR maps (Figs. 14, 16) are distinguishable because of unique combinations of soils and topography. These drainages should be evaluated to determine how they can be used to facilitate natural water delivery and promote native vegetation and thus restoration of the historic riparian, wet meadow, grassland, and shrub habitat types in these regions (Figs. 13, 21).

Water management infrastructure, either owned and operated by the refuge, or related to the Closed Basin Project, bisect many of the natural historic flow patterns on Baca NWR. Although some ditch infrastructure provides efficient flow

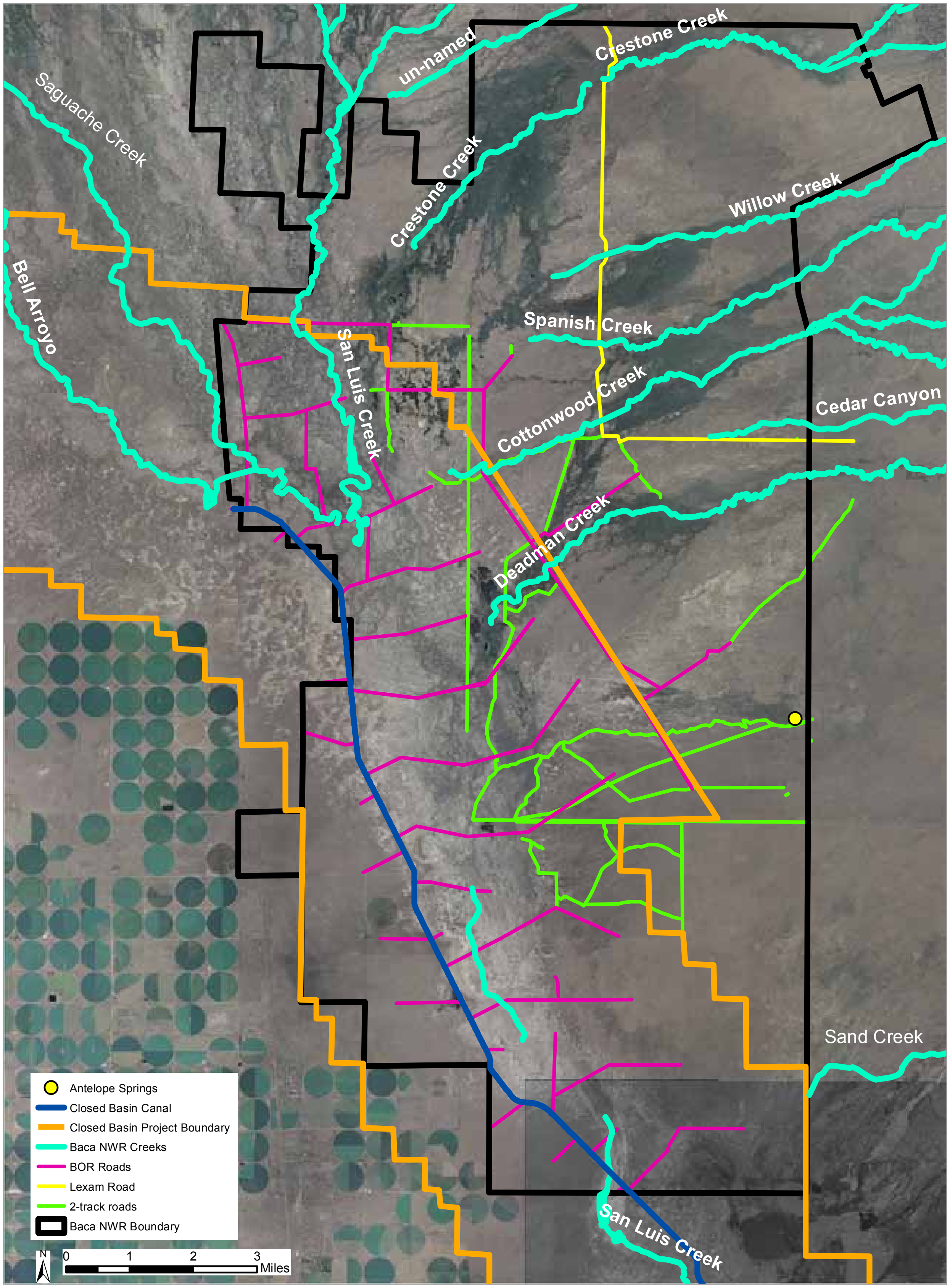

Figure 31. Bureau of Reclamation and U.S. Fish and Wildlife Service roads and ditches in relation to natural creek channels on Baca National Wildlife Refuge.

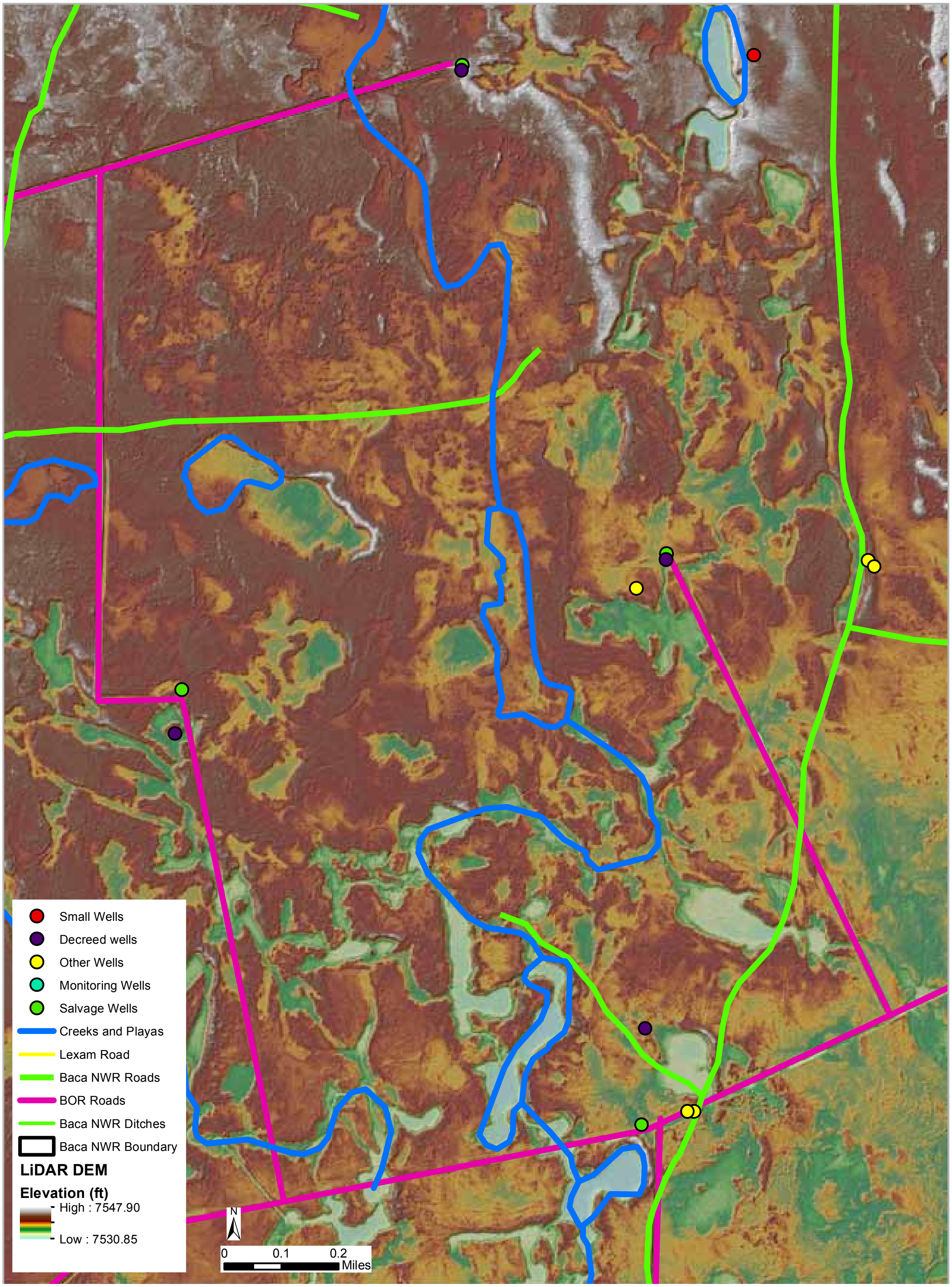

Figure 32. Bureau of Reclamation and U.S. Fish and Wildlife Service roads, water-control structures, and wells in the Upper Sump area that cross playa lakes and San Luis Creek.

of water to designated areas, many water-control structures are inactive or actually impede water flow (Figs. 24, 25). Many of these ditches and water-control structures are present throughout the San Luis Creek drainage and along Crestone, Cottonwood, and Deadman Creeks. Structures located within or immediately adjacent to creek channels have caused incision of channels throughout Baca NWR and also have re-routed some creek channels around the structure if sediment has built up behind or in it (Figs. 33a,b). Future water resources at Baca NWR, both surface and groundwater, may become more limited as unconfined and confined aquifer levels decrease, alluvial water tables decline, and climate changes cause extended drought conditions in the future. Further reductions in groundwater availability may require that water management on Baca NWR will need to prioritize water delivery to meet top priority objectives. Management of water flows through natural creek channels would reduce time, labor, and potentially costs of maintaining certain ditches, levees, and water-control structures, which require annual repair. Some water-control structures are placed outside of natural drainage patterns, set at wrong invert elevations, lack the capacity to meet the needs of flows through the system, or are in locations where soils inhibit the long-term sustainability of the structure (e.g., structures placed in sand channels) (Figs. 33a,b). Bed levels of creek channels that have become incised should be restored to allow for greater bank storage which historically helped to maintain a higher water table in adjacent grasslands and wet meadows (see Zeedyk and Clothier 2009).

Management of water flow through natural channels, across floodplains as sheetflow, and through and across natural features such as alluvial fans can help promote a more natural distribution of wetland habitat types. By moving water through natural channels on the surface and sub-surface, water tables may be stabilized and riparian willow galleries restored juxtaposed to wet meadows and grasslands on slightly higher elevation sites on the alluvial fan. Vastine, Hagga, Hapney, and Schrader soils (Fig. 13) are well suited to supporting wet meadow habitats (Fig. 21) and were historically restricted to mostly small areas adjacent to creek channels, which may have flooded regularly and had a higher soil water holding capacity. The return to a gravity fed surface water sheetflow pattern across these sites where it occurred naturally should help to promote shallowly flooded habitat type with a diversity of native vegetation based on slight changes in elevation or topographic feature. It is understood that past refuge management maintained livestock grazing and hay production (along with supporting habitat for wildlife species) (USFWS 2005). However, the long term diversion of water from creek channels to artificially create irrigated wet meadow also has destroyed many native grassland habitats and has the risk of long-term increased soil salinity in some areas, possible increased invasive species occurrence, decreased vegetation diversity, increased density and monocultures of less palatable grass and forb plant species, and gradual decrease of overall productivity. Generally, future management should attempt to more closely align water distribution, timing, depth, and duration to match soils, topography, and former wetland type locations.

Future water management strategies on Baca NWR should seek to restore natural flow through historic topographic features in a manner that emulates seasonal and inter-annual flooding and drying dynamics. During years with high spring runoff, surface water should move throughout all creek floodplains. Water management that moves water through natural topographic features can distribute water across the floodplain and can be improved by water-control structures that allow water to flow-through drainages, by moving roads to side slopes, and by eliminating lead-in and lead-out ditches from water-control structures in wet meadow locations where sheetwater flow is desired (Zeedyk 1996). Preventing artificial impoundment of water in areas where soils are not suited to a more prolonged inundation also will help prevent further invasion of weeds and promote conditions where control-treatments can help reduce current stands.

Any potential restoration activities that incorporate new development of water delivery infrastructure should be approached with caution because the Baca NWR represents an ecosystem that is more intact than most others in the San Luis Valley. Further expansion of the current water-control infrastructure runs the risk of altering historical conditions even more. Some replacement or modification of existing water-control structures may be necessary to help restore natural drainage

Figure 33. Photos of structures located within sand channels that have impeded flow, cause sediment deposition, and created artificial nick points in creek channels on Baca National Wildlife Refuge.

pathways but should be done in such a way that the structures increase the capacity of the current system to mimic the historical functioning of the area rather than increase or expand the extent of artificial water use across the alluvial fan and floodplains of the site. Specifically, construction or replacement of water-control structures in areas with sandy soils is not desirable.

2. Restore natural hydrological regimes in playa wetland systems throughout the historic San Luis Creek drainage.

The natural processes historically associated with the Upper Sump area included sediment erosion and deposition from wind and water erosion during wet and dry cycles. These processes created the playa basins; added sediments to local sand dunes and areas in the Great Sand Dunes National Park; and influenced the distribution, diversity, and seral stage of plant communities throughout the area. Climatic conditions allowing at least average snowpack and precipitation restoration of the ephemeral and sometimes perennial creek drainages referred to in the first recommendation would enhance restoration efforts to promote a more natural hydrologic regime within the playa lakes and Upper Sump area. Clearly, past management of surface water to maximize haying and grazing, along with expanded groundwater pumping and alterations in refuge topography (including the development of a complex road system associated with the Closed Basin Project), have drastically altered the hydrologic surface and subsurface flow through the Baca NWR ecosystem.

The BBG soil-land association in the Upper Sump area coincides with the historically flooded San Luis Creek floodplain and confluence areas of Sangre de Cristo creeks where playa lakes occur (Figs. 4, 13, 16, 21). These playas received considerable creek inflow in wet years, but conversely, in dry years when spring snow runoff was low many playa wetlands would remain dry. Future water management on Baca NWR should seek to emulate both wet and dry periods that mimic natural climatic cycles. The dry periods enable decomposition of organic material, wind dispersal of accumulated salts, and germination of annual herbaceous plants. Natural seasonal timing of wetland drawdown in the floodplain promotes certain species of smartweed, beggar tick (*Bidens* spp.), and goosefoot (*Chenopodium* spp.) (Fredrickson and Taylor 1982). Studies in the SLV have shown that annually consistent impoundment of water in wetlands decreases plant and invertebrate productivity and reduces waterfowl and waterbird use while simultaneously increasing sedimentation and aggradation of wetlands (Cooper and Severn 1992). Conversely, water management that provides for seasonal flooding and drying regimes creates more favorable conditions for many endemic wildlife species.

Current infrastructure on Baca NWR may not allow for natural surface water drainage to playa areas in part because of ineffective, misplaced, or the complete absence of water-control structures in levees or roads. Relocation or placement of new water-control structures within existing roads, or removal of roads (e.g. BOR roads providing access to salvage or monitoring wells, Fig. 31), would allow surface water runoff to flow into playas and the historic San Luis Creek channel. The relocation or placement of adequately placed water-control structures to allow for sheetflow, while preventing artificial "ponding" or the impoundment of water next to levees and roads also is important to re-establish natural hydrologic regimes and vegetation communities. Existing roads throughout the refuge (Figs. 3, 31, 32) have impacted natural sheetflow to the Upper Sump area. Specific areas in the Upper Sump where modification of roads may facilitate system restoration include areas just west of Weisman Lake. Currently, many roads exist in this area that contain inactive water-control structures, end abruptly, and cross playa basins and the San Luis Creek channel (Fig. 32). Roads that extend into or cross playa basins should be removed or should incorporate structures that allow water to move across or through them in a sheetflow manner. Other factors such as wells within playa lakes and adjacent to creek corridors may negatively impact natural flow of surface and sub-surface water if they are allowed to flow or are pumped. Utilizing wells which artificially provide surface water and locally reduce the water table negatively impacts playas. For example, a lower unconfined aquifer water table may preclude maintaining surface water in these areas as water applied to the soil surface may immediately infiltrate until soils are saturated again, which may or may not occur given limited water resources.

3. Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes.

The distribution and extent of former riparian, wetland, grassland, and shrub habitats on Baca NWR was related to geomorphology, soil type, elevation, and seasonal and inter-annual hydrological regimes of the ephemeral Sangre de Cristo creeks and San Luis Creek. The HGM map of the potential former distribution and extent of these habitats provided in this report offers a guide to where potential future restoration and water management of all habitat types can occur (Fig. 21). The changes in the area and distribution of habitat types from the late-1800s to the current time on Baca NWR include: 1) the conversion of formerly drier regime later succession sagebrush on some areas of the alluvial fans, dunes, and sand sheet to rabbitbrush or transition shrub-grassland type habitats, 2) conversion of grasslands to wet meadow or greasewood/rabbitbrush shrub habitats, 3) the reduction in extent and health of the riparian forest gallery, and 4) the continued invasion of exotic weeds into all habitat types.

By the time Baca NWR was established and acquired in the early-2000s, many refuge areas had been irrigated to increase hay and pasture areas for over a century (Reddin 1979, USFWS 2005, Eddie Clayton personal communication). Further, part of the legislation that established Baca NWR directed the refuge to continue irrigation of meadows. The collective effect of SLV water use, loss of dynamic creek processes, and long-term irrigation to promote annual forage production for haying and grazing gradually diminished local alluvial aquifers and altered vegetation communities as discussed above. The eventual conversion of potential sagebrush habitat to early seral shrub species that are more tolerant of saline conditions such as rabbitbrush and greasewood (Tilley et al. 2005, Tilley and St. John 2012) on Baca NWR indicate that historic and current land/water management strategies have promoted the conversion of this habitat type. Currently, little to no sagebrush exists on Baca NWR although four-winged saltbush (*Atriplex canescens*), a species often associated with sagebrush communities (Taylor 1992), does exist in soils and topographic locations similar to those required for sagebrush. Flood irrigation and/or grazing and mowing of upland shrublands, especially on the sand sheet surfaces, on Baca NWR likely will continue to promote rabbitbrush and greasewood in upland areas. Irrigation and management of shrublands juxtaposed to creek corridors on the refuge historically was done irrespective of soil type on the refuge (Figs. 13, 21, 23, 27) and without consideration of particular characteristics and responses of different shrub and grass species to various disturbances. Specifically, yellow and rubber rabbitbrush are early seral species that become established after disturbances and they may continue to exist as secondary shrub species over time should disturbances cease. Disturbances such as overgrazing, mowing, and burning allows these species to outcompete sagebrush, which is extremely sensitive to burning and mowing (Tilley et al. 2005; Tilley and St. John 2012; Chambers et al. 2009).

Rabbitbrush and sagebrush provide wildlife, and to some extent livestock, with forage during different times of the year (Tilley and St. John 2012) in addition to providing various resources for other species such as songbirds and small mammals. As sagebrush diminishes in shrublands, associated plant species or forage in general declines (Tilley et al. 2005). Grasses associated with this community depend on the sagebrush to transport water up to the surface which then becomes available to not only the shrub itself but surrounding grasses. Thus, the sagebrush creates specific conditions which increase the diversity, density, quality, and health of the system. Mountain big sagebrush (*Artemisia tridentata var. pauciflora*) is long-lived and constitutes up to 40 to 50% of the total plant cover in some upland areas after 50 years. Historically, this community may have included a secondary species, low sagebrush (*Artemesia arbuscula var. arbuscula*), which still occurs in small patches further north in Saguache County on low windswept ridges (Winward 2004). Fire frequency in sagebrush shrublands may vary from 30 to 100 years dependent upon local soil conditions, precipitation, productivity, and topography with salt desert shrublands having the lowest fire return interval. The use of fire in these systems in combination with removal of shrubs can cause up to a thirty fold increase in invasive weeds (Chambers et al. 2009). Therefore, the use of prescribed fire over short-term intervals in historic shrub dominated areas would be detrimental to restoration strategies.

Changes to the historical hydrological regime (e.g. lack of perennial flows from La Garita, Saguache, and San Luis creeks) that provided water to the playas and former grassland sites adjacent to them in the Upper Sump, along with removal of groundwater from these areas, have altered the flood frequency and depth to the groundwater table, gradually increased soil salinity through capillary action of soils and deposition of evaporative salts on the soil surface, and caused some sites to become highly alkaline even to the point of creating barren salt flats. Over-grazing of grasslands also has been shown to increase the distribution and cover of shrub species such as greasewood (SCS 1981), which is apparent when comparing the HGM potential historic vegetation (Fig. 21), current vegetation map (Fig. 28), soils (Fig. 13), and the grazing and haying that has occurred over the past century on Baca NWR (Fig. 30). Currently, greasewood dominates areas adjacent to the Upper Sump and playas, where it may have existed historically in small areas or clumps on the Baca NWR. The soils present in the area indicate that grasses should be the dominant vegetation type (SCS 1981).

Former grasslands in the north and east portions of Baca NWR were more extensive than they are currently and they historically were present on loamy sand or sandy loam areas (Figs. 13, 21, Table 3). Grasslands may have existed adjacent to wet meadows that paralleled creeks. The account of Gunnison's Expedition in 1853 (Unknown 1970) indicates the group passed over what appears to have been North and South Crestone Creek from which they could "see fine prairie-grass fields" stretching out towards the interior of the valley. The GLO survey (Fig. 5) indicates expanses of *Artemisia* throughout the historic Baca Grant #4. Accounts from the early-1920s observed that even in dry years, grasslands were dense and productive (Reddin 1979), suggesting that groundwater levels may have helped maintain the growth of these areas even during periods of lower than normal precipitation.

Over time, the riparian willow habitats on Baca NWR, especially along Deadman Creek, have become restricted to narrow bands with little to no regeneration or do not exist at all. Reductions in riparian habitats have been caused by a variety of factors, including reductions in creek flows, lowered water tables, past management including water management strategies that distributed flows out of creek channels and reduced bank storage, haying, and herbivory by elk and cattle. Generally the historical and natural dynamic functions of the creeks have been reduced or do not occur at all, which prevents future scouring of floodplain depressions and channels while increasing the amount of organic material present on the soil surface. A heterogeneous age class and structure within riparian willows is essential to the survival and maintenance of most wildlife species that use these habitats for winter shelter, forage, migration, and movement corridors (Scott et al. 2003, Skagen et al. 2005, Shafroth et al. 2000). Current soil series mapped to creek areas in their upper reaches, where willow historically may have been most common, do not indicate that they are uniquely structured for willow growth. Topographic features such as natural levees along creek channels may be sites that are suitable for the regeneration of cottonwood and/or early seral willow species if natural water regimes can be restored and management strategies such as haying and mowing can be altered to provide alternative forage species combined with a reduction in herbivory.

Specific areas on Baca NWR with good options for restoration of native vegetation communities include areas along and between Crestone and Willow Creek, and Deadman and Cottonwood Creek. While the natural topography and water flow patterns at Baca NWR have been altered, some opportunities exist to modify existing water diversion and control infrastructure and restore more natural patterns of surface and sub-surface water flow through natural creek drainages (see previous discussion for recommendation #1 above). Infrastructure that is inactive or impedes creek flow within its natural creek channel should be removed or modified. Several ditches distribute Crestone Creek water to the north and south of the channel. Of note is the ditch that begins flowing west and then branches southwesterly and southeasterly across the alluvial fan to Willow Creek. Most of the water-control structures associated with this ditch system are inactive. A third ditch extends uphill from Willow Creek to the north, gaining a foot in elevation, before ending abruptly (Fig. 34a). Two refuge roads extend out into the alluvial fan from the north and east and end abruptly. Roads, ditches, and water-control structures that bisect, impede flow, or are not operational and located on the alluvial fan in historic upland shrub and grassland areas should be removed where possible (Fig. 34b). Currently habitat transition areas now occur where historically grasslands probably existed (Figs. 34b,c). Removal of infrastructure may allow for a more natural hydrologic regime that will favor native grass species rather than herbaceous understory species in shrublands that may be prime locations for invasive weeds. Improving natural surface water flow through natural topographic features such as Crestone Creek that allows subsurface flow and dispersal throughout the floodplain and alluvial fan can be increased through the correct placement of water-control structures and the elimination of ditches radiating from certain structures in wet meadow areas (Zeedyk 1996). Restoration of the riparian willow gallery also may be promoted if overbank flood events are restored.

The Deadman and Cottonwood Creek area also has many roads and ditches that bisect the alluvial fan and contain inactive water-control structures. Specifically, BOR roads cross Cottonwood Creek multiple times before finally heading south to cross Deadman Creek and bisect a playa lake. Ditches carry water from both creeks to a point midway between them. Each of the ditches contains inactive water-control structures. Historically the area between the two creeks that is now bounded to the west by ditches was grassland (Figs. 35a,b). This area now has been converted into a shrub-grassland transitional habitat type (Fig. 35c). A road makes a loop within this habitat type further interrupting hydrologic surface flow. Removal of the inactive water-control structures, the two converging ditches, and road loop in this area would greatly enhance a more natural hydrologic regime across the alluvial fan and promote the conversion of the area back to grassland. Relocation of the road that continuously crosses Cottonwood Creek would help promote natural flow in the creek and allow for potential re-growth of native riparian and grassland species. Relocation of the road running generally north south which bisects the playa (Fig. 35a) would promote flow-through drainage and a more natural hydrologic regime in this area. Currently a BOR road crosses

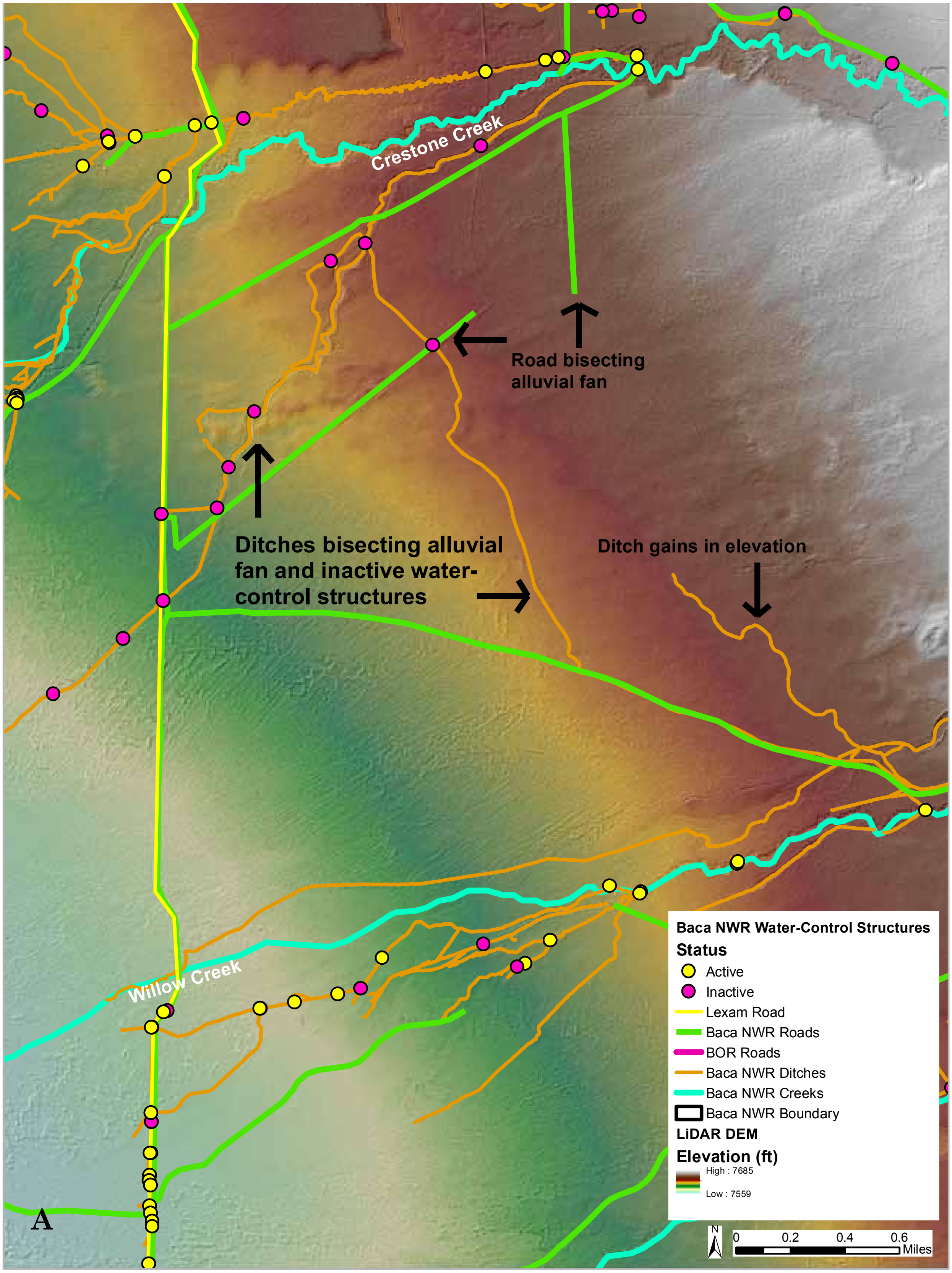

Figure 34. Potential restoration of Crestone and Willow creeks, grasslands, and shrublands on Baca National Wildlife Refuge in relation to: a) elevation, b) HGM potential historic vegetation and existing infrastructure, and c) current habitat types and existing infrastructure.

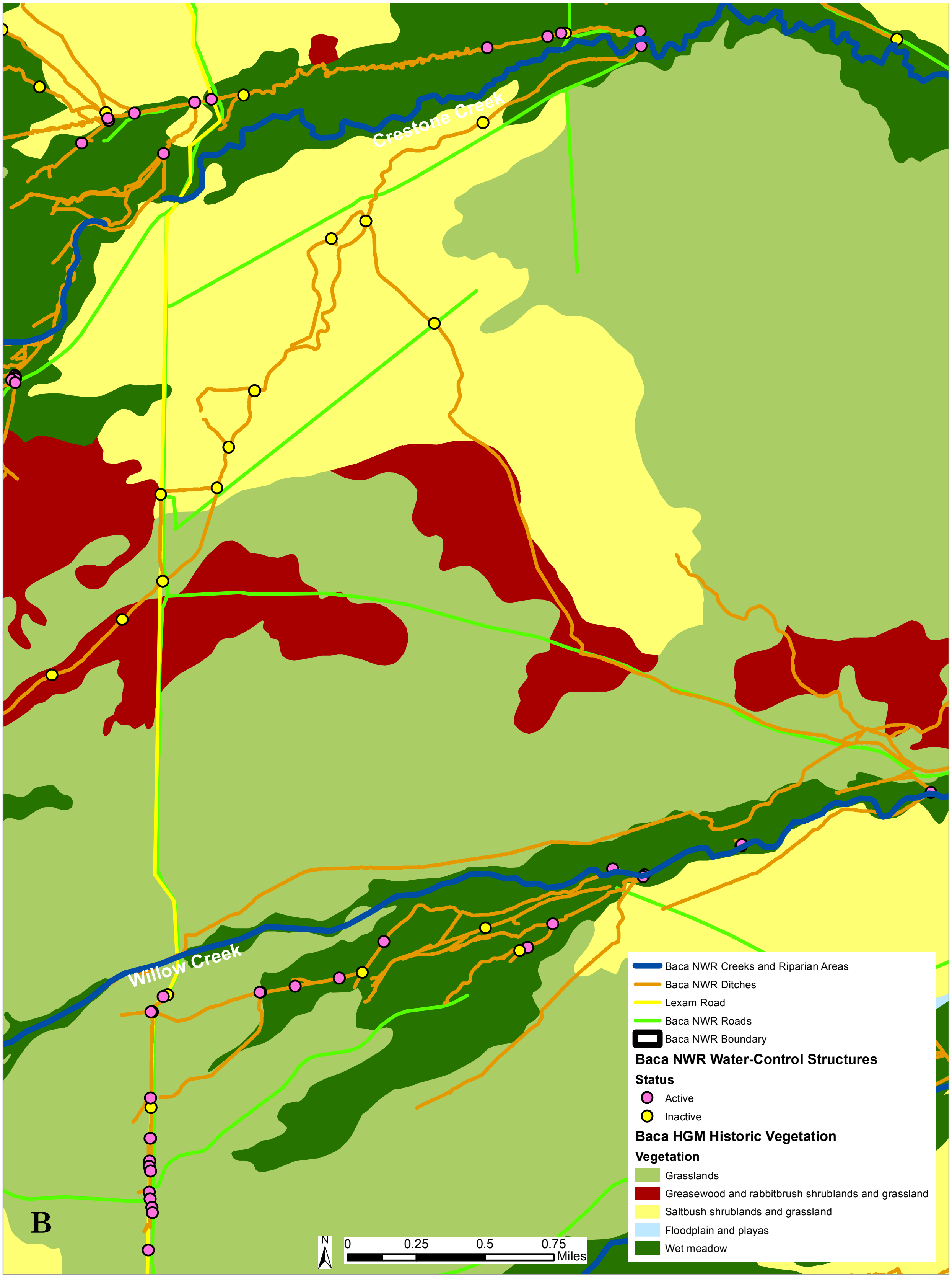

Figure 34. Potential restoration of Crestone and Willow creeks, grasslands, and shrublands on Baca National Wildlife Refuge in relation to: a) elevation, b) HGM potential historic vegetation and existing infrastructure, and c) current habitat types and existing infrastructure.

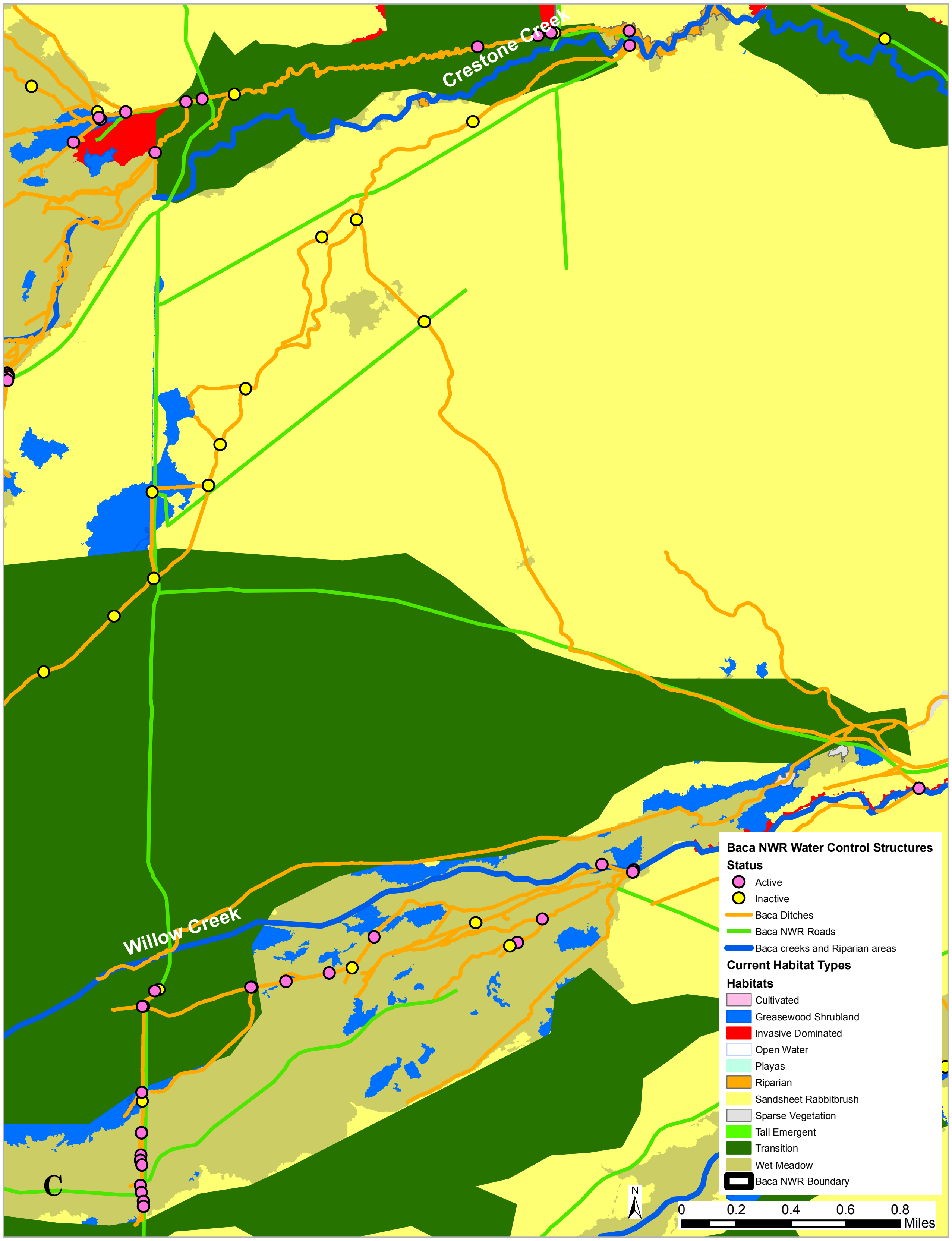

Figure 34. Potential restoration of Crestone and Willow creeks, grasslands, and shrublands on Baca National Wildlife Refuge in relation to: a) elevation, b) HGM potential historic vegetation and existing infrastructure, and c) current habitat types and existing infrastructure.

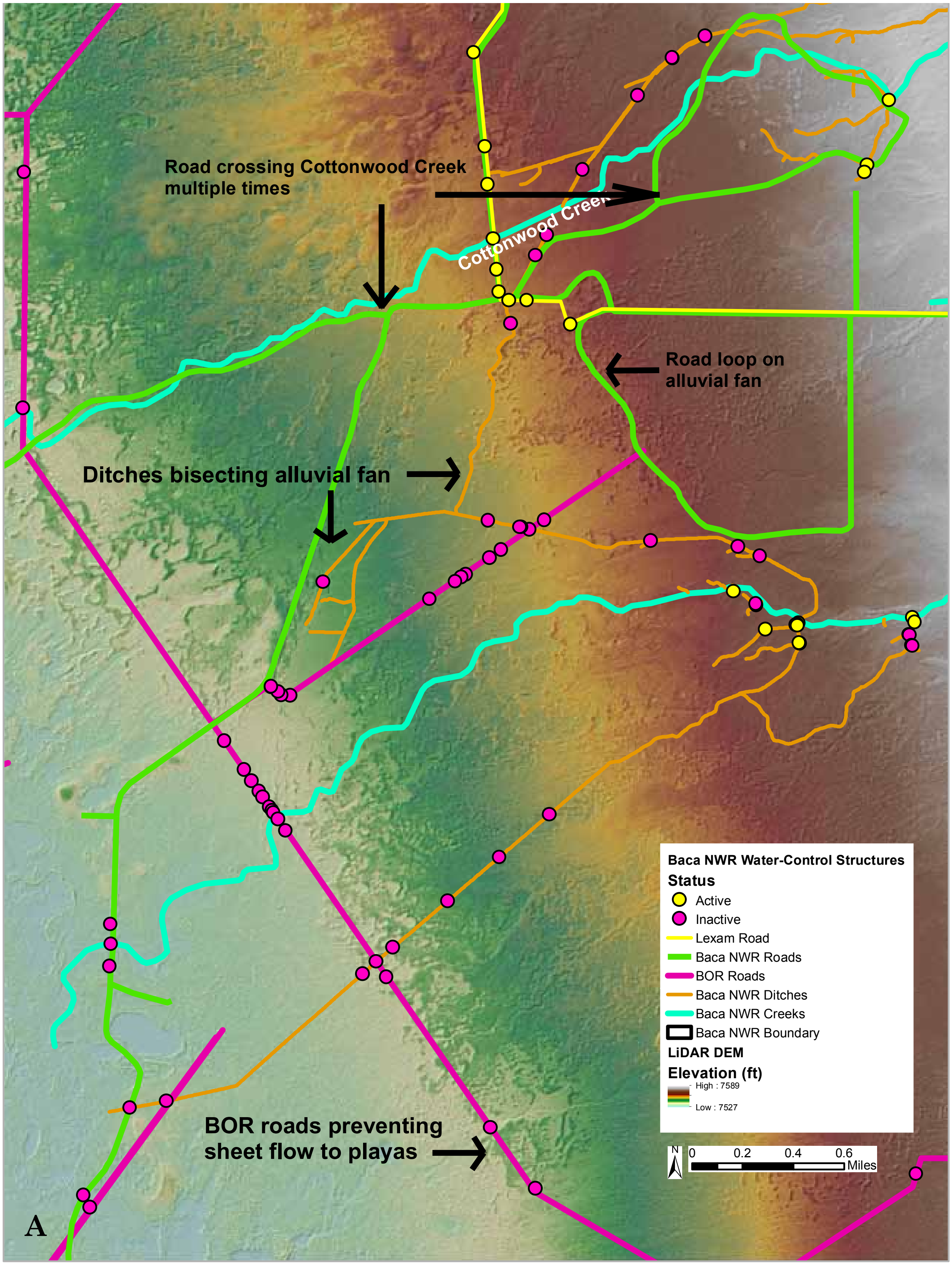

Figure 35. Potential restoration of Deadman and Cottonwood Creeks, grasslands, and shrublands on Baca National Wildlife Refuge in relation to: a) elevation, b) HGM potential historic vegetation and existing infrastructure, and c) current habitat types and existing infrastructure.

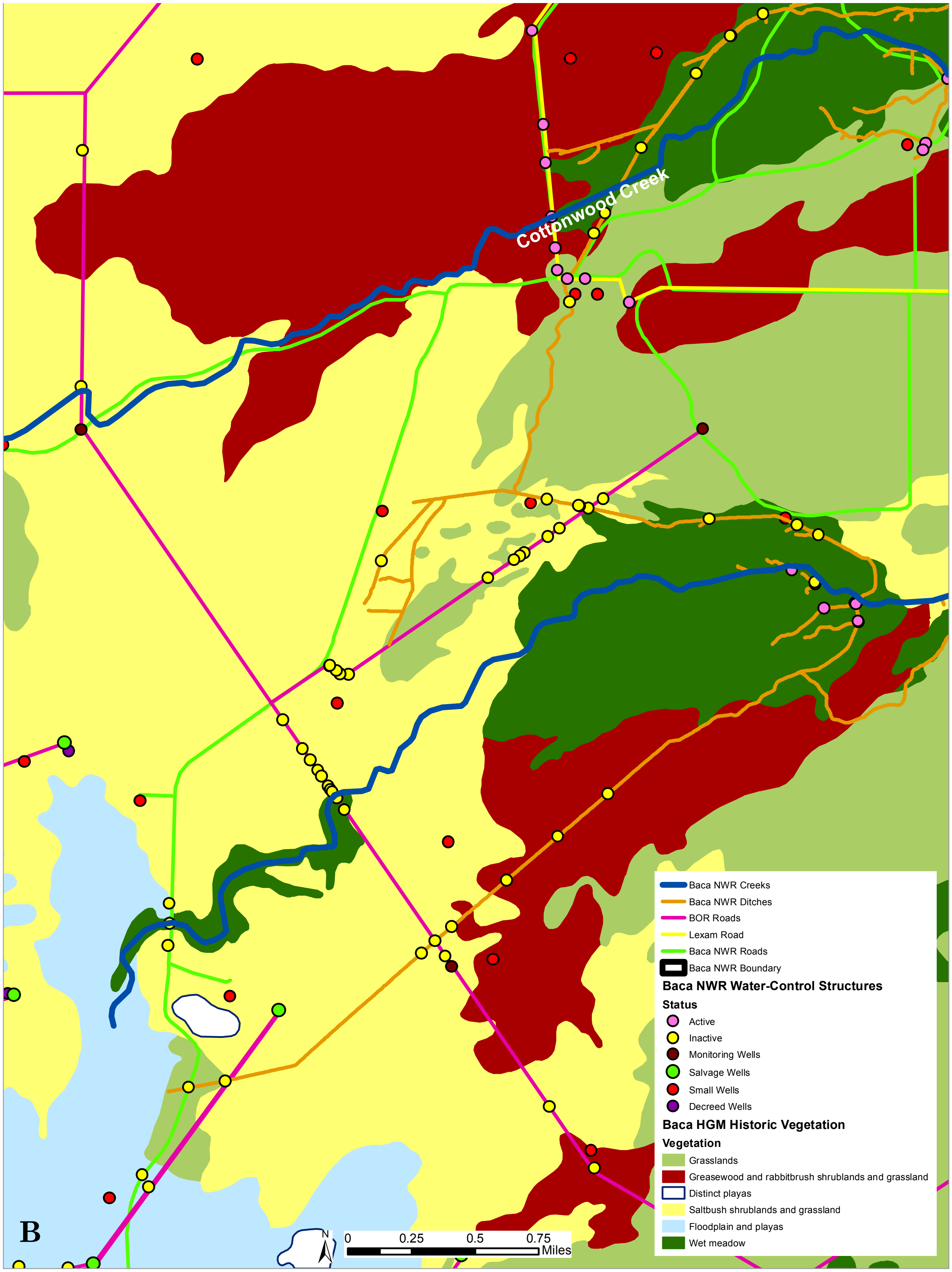

Figure 35. Potential restoration of Deadman and Cottonwood Creeks, grasslands, and shrublands on Baca National Wildlife Refuge in relation to: a) elevation, b) HGM potential historic vegetation and existing infrastructure, and c) current habitat types and existing infrastructure.

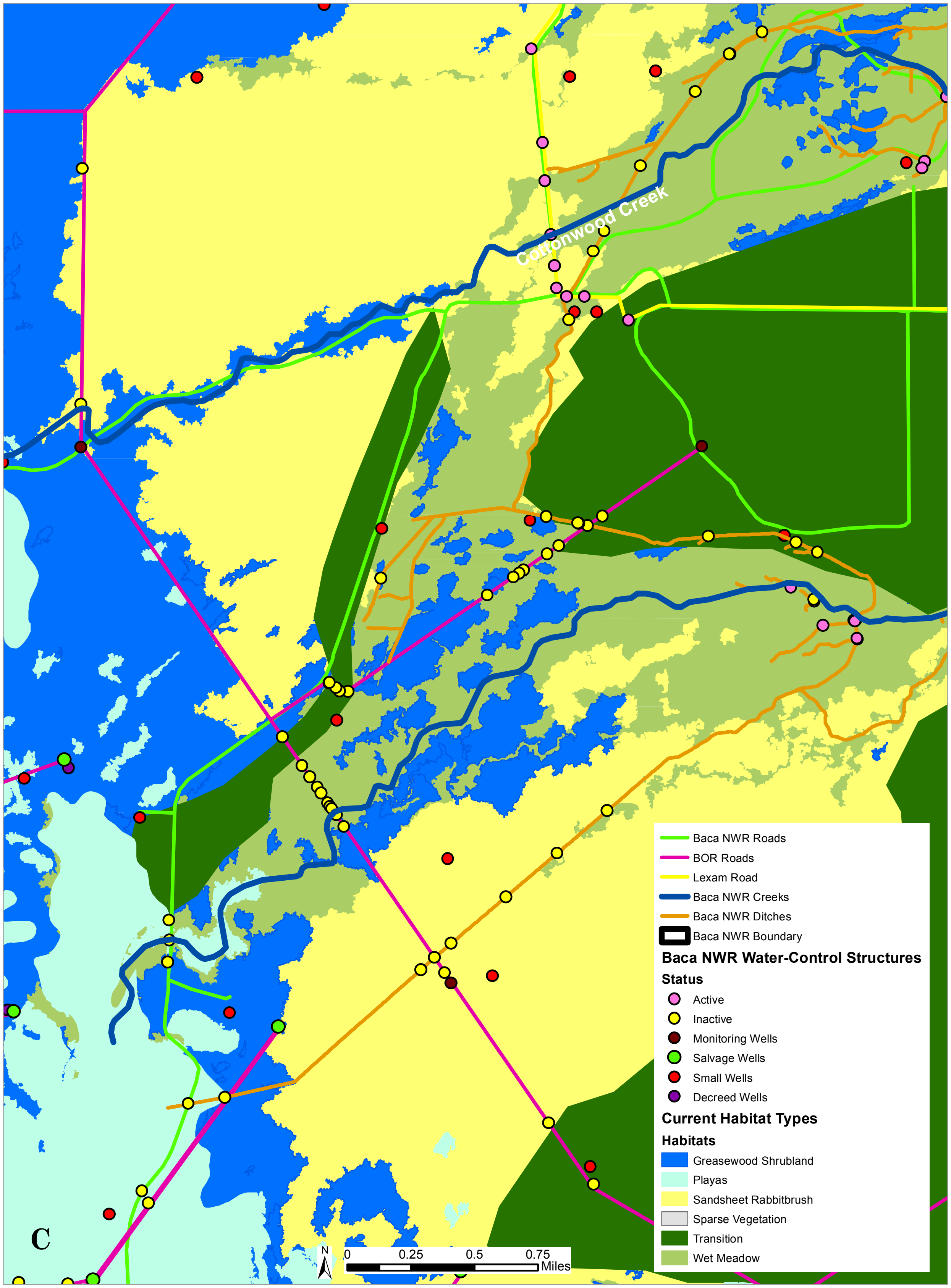

Figure 35. Potential restoration of Deadman and Cottonwood Creeks, grasslands, and shrublands on Baca National Wildlife Refuge in relation to: a) elevation, b) HGM potential historic vegetation and existing infrastructure, and c) current habitat types and existing infrastructure.

Deadman Creek, which contains many currently inactive water-control structures due to low levels of precipitation and upstream impediments to flow. Removal of infrastructure that impedes this flow and/or use of existing structures that will enhance or promote natural flow will help restore the natural hydrologic regime to this drainage.

*4. **Manage herbivory in riparian areas, wet meadows, grasslands, and shrublands to emulate natural processes and conditions.***

Historical habitats located on Baca NWR developed in concert with natural herbivory from a variety of large native ungulates. These ungulate species probably would have been present in large herds for short time intervals as they moved to other sites with available resources and returned when the forage they consumed had recovered. Specific forage that contains specific minerals, nutrients, or protein may have attracted these species to the area during certain times of the year when animals had specific physiological needs. For example, yellow rabbitbrush (*Chrysothamnus viscidiflorus*) may be targeted by ungulates after other species like sagebrush and grasses have been consumed, because it is less desirable but still offers some nutrition in the late fall and early winter (Tilley and St. John 2012; Tilley et al. 2012). Rubber rabbitbrush may be toxic during the summer but provides necessary crude protein and phosphorous in the winter (Scheinost et al. 2010). Currently, natural grazing by wildlife species cannot occur due to a variety of reasons including property infrastructure, roads, conflicts with landowners, artificial movements of herds due to hunting pressure, etc. Furthermore, extensive historical upland shrublands have been altered including a reduction in the associated herbaceous layer on Baca NWR. Century-long haying and grazing of livestock has probably been a major factor in the loss or conversion of many of the habitat types on the refuge.

While the historical extent of sagebrush on Baca NWR is unknown, overgrazing may have been one of the factors, along with lower water tables and reduced fluvial dynamics that ultimately led to the almost complete loss of sagebrush on refuge lands. A large winter population of elk over the past 20 years also has intensively grazed riparian willow gallery areas. Increased use of willow stands on the Baca NWR by elk may be due in part to the decline of historic native vegetation communities that ungulates depended upon for forage throughout the year. For example, mountain big sagebrush is one forage species selected by elk during the winter (Hansen and Reid 1975). This species provides forage and also necessary habitat conditions for a variety of other undershrub grasses because its root structure traps and holds water, then releases it during the night near the surface, making it available to a variety of grasses and forbs (Tilley et al. 2005). Overall decreases in the amount of forage availability have been linked to the complete eradication of this species from vegetative communities which were being managed to increase grass species (Tilley et al. 2005). Comparisons of the HGM potential historic vegetation (Fig. 21) and the current habitat types on the Baca NWR (Fig. 28) indicate that there has been a conversion of shrubland to either rabbitbrush-dominated shrub or transition-type shrub-grassland. Rubber and yellow rabbitbrush are early seral species adapted to disturbance, which promotes its growth and cover, allowing it to expand and dominate areas that were previously primarily dominated by sagebrush (Tilley and St. John 2012, Scheinost et al. 2010). Continued disturbance using management strategies involving mowing, burning, grazing, or herbivory will continue to promote complete dominance by rabbitbrush species (Chambers et al. 2009). This conversion may have helped to promote ungulate use of willow riparian areas exacerbating potential declines in willow abundance throughout the region due to changes in hydrological regime and a lack of fluvial processes. Changes to these vegetation communities not only has impacted wildlife and cattle forage, but has ultimately affected the hydrologic regime resulting from alterations in root distribution and morphology, reduced cover and increases in bare ground, increased erosion, and through cattle and ungulate movements in active creek channels and banks.

Future adaptive management of livestock and elk, coupled with the other recommendations mentioned above, will help restore natural hydrologic regimes, increase the health and quality of native grasslands, and increase the availability of native forage species for a variety of wildlife species. Providing different habitat types that incorporate a variety of forage species throughout the year should help reduce overgrazing and overbrowsing of distinct habitat types such as riparian willow galleries. However, stocking rates, duration, and seasonality when livestock are allowed in certain habitat types should be carefully planned and monitored in order to support restoration efforts. Therefore, potential grazing rotations should incorporate shorter durations in smaller units to accurately monitor the amount that is consumed, and move livestock onto new pastures before overgrazing has occurred. Temporary fencing can be used to easily adapt the size and shape of pastures in order to impact specific vegetation communities. Other factors to consider include whether or not the plant species are C3 or C4, cool season or warm season grasses, respectively. For example, cool season grasses grow in cooler temperatures starting early in the spring, becoming dormant in the summer, and growing again in the fall. Warm season grasses require warmer temperatures before growth can begin. Therefore, grazing of these species should be done with the knowledge of which plants belong to each group as each group withstands defoliation better during certain times of the year. Cool season grasses may be grazed without harming regrowth potential in the fall, winter, and early spring whereas warm season grasses should be grazed after tillers (roots) have begun growing in the summer (Hannaway 2000). Grazing may be used in some areas to assist in weed control, specifically for tall whitetop (Diebboll 1999, Gardner 2002). Rosettes and early stems may be eaten by cattle, although later growth stages are avoided. Thus, timing of grazing will influence the effectiveness of this strategy for controlling this weed.

Management of grazing in potential riparian woodland areas will require different strategies than management of grasslands, including fencing or exclusion areas, longer-term rest, seasonal timing, stocking rate, and age class of livestock. Some plant and tree species in riparian areas may be more sensitive to browsing and grazing during specific plant growth periods or seasons (Leonard et al. 1997). For example, selecting specific associations of age classes such as cow-calf pairs or yearlings will impact different plant species based on the time of year and their unique nutritional needs. Although the floodplain of the Rio Grande is more extensive than the Sangre de Cristo creeks, many of the same shrub, herbaceous, and tree species are similar, as are issues with little to no regeneration of willow and cottonwoods. Recent changes in grazing management have made considerable improvements in the health and density of native species in wet meadows on private lands along the Rio Grande (Cynthia Villa personal communication), which should be comparable to potential restoration strategies recommended for Baca NWR. Specifically, cattle have been rotated through small pastures, grazing for a few days, before moving onto another pasture to prevent plants from being over-defoliated. Plants are allowed to fully re-grow and may be grazed again or hayed, but not both.

SPECIFIC RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

1. Restore natural water pathways and processes where possible in Crestone, Cottonwood, Willow, Spanish, and Deadman Creeks.

- Restore water distribution to historic drainages and allow creeks to overflow banks and distribute sediments across floodplains. Manage water delivery through ditches, levees, and roads that will improve natural flow through drainages and replace water-control structures that do not have adequate flow-through capacity or that are restricting water flows.
- Restore natural creek bed elevations in areas where creeks have been incised to promote overbank flood events, higher groundwater tables, bank storage, and regeneration of riparian willow (see Zeedyk 1996, Zeedyk and Clothier 2009).
- Manage water in natural creek drainages in wet years to provide surface flows to the San Luis Creek and playa wetlands in the Upper Sump area.
- Restrict development of new water delivery infrastructure that will compromise the natural flow of surface water in natural drainage pathways.

- Develop a strategic water management plan that identifies specific objectives for the distribution and timing of water resources and also includes documentation of the conditions that will occur related to management actions.
- Prevent ponding of water along roads or levees where it prevents surface water drainage and sheetflow across the area. Evaluate BOR roads and determine if any cooperative efforts may occur to remove or restructure roads and associated water-control structures to promote sheetflow and prevent impounding water (Fig. 32), especially roads that intercept creek drainages on the east side of the CBC.
- Work with BOR to restrict pumping of shallow unconfined wells that locally diminish groundwater levels and negatively impact grasslands, particularly those adjacent to creek drainages. Reducing withdrawals from the shallow unconfined aquifer should help in preventing cones of hydrologic depression and promote a more stable and continuous water table. Currently very few decreed wells exist on the refuge and most are either small or listed as "other"; however, they may be negatively impacting creek flows given their close juxtaposition to them (Figs. 7, 26).
- Closed Basin Project wells have an effect on the water table within the Baca NWR. Should the opportunity become available, refuge staff should pursue cooperative efforts to cap or decommission wells administered as part of the project and remove any of the unused infrastructure that exists in any and all habitat types, (e.g. ditches, roads, water-control structures).
- Remove inactive water-control structures along Crestone, Cottonwood, and Deadman Creeks (Figs. 24, 34, 35). These structures may be impacting water flow by restricting or diverting water in the creek channel.
- Restoration of incised streambed levels is desirable at a refuge-wide scale at Baca NWR. This restoration, however, will likely need to occur stream-by-stream based on refuge resources and priorities. Zeedyk and Clothier (2009) provide a wide range of examples of strategies that may be used depending on the type of erosion that has occurred and in relation to landscape setting.

2. ***Restore natural hydrological regimes in playa wetland systems throughout the historic San Luis Creek drainage.***

- Manage playas on clay loam soil types, including the Biedell, Hooper, and Hapney clay loams within the Upper Sump region of the Closed Basin (Figs. 5, 13, 21).
- Allow playa basins of various sizes to dry out including larger ones such as Weisman Lake, mimicking the short-term dry-wet cycle (Fig. 16).
- Mimic natural hydrologic regimes so that playas are flooded in late spring and early summer and then naturally drawn down.
- Allow natural flow-through of water in playa basins during high water years.
- Remove infrastructure that promotes prolonged impoundment of water in natural playa basins. Specifically remove water-control structures that lie within playa habitat (Figs. 16, 21, 32, 35) that are restricting flow through playas, impounding water within the historic San Luis Creek, or otherwise preventing natural flow to and through this area.
- Remove ditches and roads that alter water flow adjacent to playas or within playas (Figs. 32, 35) and that currently drain or prevent surface water sheetflow.

3. ***Restore and manage the distribution, type, and extent of natural vegetation communities in relation to hydrogeomorphic attributes.***

- Restore and manage wet meadows on Vastine, Hagga, Hapney, and Schrader soils adjacent to creek channels on the alluvial fan (Figs. 13, 21).
- Manage water regimes in wet meadows to emulate spring seasonal inputs of water and inter-annual wet vs. dry regimes. Vary annual flooding regimes of wetland areas among years to emulate periods of natural

drought or more extended flooding at short term, 5 to 7 year intervals of peak-to-peak and low-to-low patterns described in the Water Resource Inventory Assessment (WRIA) (Striffler 2013; Fig. 15).

- Allow flash flood events in late summer and early fall that are caused by monsoonal rain events to access wet meadows and promote dynamic flooding regimes.

- Restore former grasslands in loamy sand or sandy loam soil types (Table 3) adjacent to and in-between creek drainages on alluvial fans (Figs. 13, 21). Specifically remove roads, ditches, and water-control structures that bisect the alluvial fan between Crestone and Willow Creek and between Cottonwood and Deadman Creek (Figs. 34, 35).

- Prevent artificial impoundment of water in areas mapped as HHH and SCC soil-land associations on alluvial fans. These areas are best suited for restoration of grasslands or upland shrub habitats (Table 3; Figs. 21,28).

- Restore former riparian willow areas along the higher elevation upper reaches of Deadman Creek. Early succession riparian woodland typically supports narrowleaf cottonwood and sandbar willow in areas not more than three to six feet above the high water table marks (Carsey et al. 2003). Prevent haying and grazing/browsing from occurring along this drainage with several permanent exclosures in areas that currently contain remnant stands of willow. Restoration of these vegetation components will help naturally slow water down within creek channels and promote bank storage of water, which will help dampen changes in the water table in adjacent areas. Specifically, remove or replace ineffective water-control structures in roads that bisect the creek and potentially impound water. Remove ditches that transport water to areas that water in the natural creek drainage could access if water was left in the channel (Fig. 35). Restore creek bed levels to improve bank storage and improve the water table in adjacent habitats.

- Restore former upland shrubland habitats on HHH and SCC soil-land association areas (currently described as rabbitbrush sand sheet alliance Fig. 28) and allow precipitation events to drive temporary wetland distribution throughout inter-dunal swale areas. Further evaluation of the historical composition of upland shrubland areas is needed to determine if and where sagebrush may have occurred and then to develop appropriate restoration strategies to restore native species assemblages. One type of restoration strategy that has been successful suggests that sagebrush seed can be broadcast in fall and then land-imprinted into the soil no more than 1/8 inch or directly sown on snow for best results (Tilley et al. 2005).

- Remove (if possible) all unnecessary dikes, ditches, and water-control structures that promote long-term flooding, ponding, or prevent sheetflow through the system, especially in areas which have been converted from one habitat to another (e.g., prevent flooding in areas mapped as HHH or SCC soil-land associations outside of topographic features such as inter-dunal swales).

- Manage large playa basins for natural seasonal and inter-annual flooding and drying dynamics to promote native species complexes and avoid monocultures of some species, such as extensive stands of emergents like softstem bulrush that become present when extended water levels are maintained over several years. Ramaley (1942) provides examples from San Luis Lake documenting the changes over time of vegetation communities from expanses of bulrush during wet years to the encroachment of greasewood during dry years coupled with reduction of bulrush.

- Control invasive plant species in wetlands, riparian areas, grasslands, and shrublands and promote re-establishment of native species composition, diversity, and distribution. Prevent fires in newly seeded and established sagebrush areas in order to promote native vegetation growth (Tilley et al. 2005). Overall, fire should be used with caution within historic shrublands if restoration is the goal. Prevent mowing of rabbitbrush in weedy areas as this disturbance will allow weeds to flourish (Scheinost et al. 2010; Tilley and St. John 2012). Conduct herbicide applications where necessary to reduce Russian knapweed, tall whitetop, and tamarisk invasions in these areas where mowing, burning, and grazing will conflict with restoration efforts.

- Prevent further conversion of transition, wet meadows, and shrubland (Fig. 28) areas through prolonged or unnatural flooding of soils that support these communities. Tall whitetop is maintained and established through changes in hydrologic patterns, and diversion of water into upland areas carries seeds and provides conditions for establishment. Roots can then grow in subsequent years to several meters depending on the depth of the water table.

4. ***Manage herbivory in riparian areas, wet meadows, grasslands, and shrublands to emulate natural processes and conditions.***

Natural ecological processes along the ephemeral creeks draining from the Sangre de Cristo Mountains have been altered or eliminated by the construction of ditches and diversions. Groundwater wells have further altered the distribution of surface water and lowered local water tables. Intensive haying and grazing over many decades further changed the vegetation composition of riparian areas, wet meadows, grasslands, and shrublands where native ungulates became concentrated and foraged throughout the year. Hunting pressure on private lands and adjacent public lands along with the introduction of livestock has altered the movements and distribution of native ungulate populations on Baca NWR. Specific management actions that could help restore native vegetation in relation to natural herbivory include:

- Restore native upland shrubland and associated undershrub grass/forb species to promote alternative winter forage (see recommendation #3).

- Restore native grassland species and natural hydrology across the alluvial fan in the north and eastern portion of the refuge (see recommendations #2 and 3).

- Haying and grazing practices on Baca NWR have been fairly consistent over the last century. Consider removing livestock grazing and haying from creek corridors for some extended period of time, especially along Deadman Creek, to restore riparian habitats. Some information exists indicating that the time and duration of potential herbivory are important factors in preventing overgrazing of cottonwoods, and suggested that the diversity and complexity of newly established cottonwood and riparian forests are negatively impacted by grazing regardless of the age of the stand (Scott et al. 2003). Monitoring and evaluation of grazing management strategies will be important to the success in re-establishing riparian woodland.

- Rotate livestock among smaller grazing units during different times of year. Livestock and native ungulates may target different forage species depending on the time of year, ultimately impacting some shrub or grass species at a critical time that may prevent full recovery. For example, rabbitbrush species may be consumed based on season or specific dietary needs of certain ungulates. Yellow rabbitbrush will only be grazed after more preferable forage is consumed (Tilley and St. John 2012), whereas rubber rabbitbrush can be poisonous during the summer (but not in other seasons) and is utilized a majority of the time by a specific ungulate such as mule deer (Scheinost et al. 2010). Determine dominant plant phenologies and identify plant species within pastures to determine if they are cool or warm season-dominated and then design grazing programs according to the respective growth stages of plants to prevent over defoliation (Hannaway 2000).

- Consider alternative management strategies to reduce or redistribute the elk population throughout the refuge or seek cooperative efforts with adjacent public land agencies such as the NPS, CPW, and TNC. Some dispersal hunts have occurred on the refuge. Continued regulated hunts on the Baca NWR may help to disperse the elk to other locations and reduce past issues with adjacent landowners and hunters as well as reduce over browse of riparian willow areas and allow restoration efforts in shrub and grass areas to be successful.

- Delay the reintroduction of native ungulate species such as bison that may impact current or restored vegetation communities until existing over-browsed conditions have been controlled and herbivory and grazing is better understood in relation to the plant species present and when restoration efforts in various habitat types have been successful.

Cary Aloia

MONITORING AND EVALUATION

The current understanding of the historical condition of the Baca NWR ecosystem is limited because little to no written documentation of specific past management strategies or the abiotic and biotic conditions of the area over time exists. Historical accounts, newspaper articles, current vegetation and wildlife surveys, and personal communications with past land managers have provided the bulk of the information for this report relating to management strategies and changes in vegetation and animal communities. Detailed topographic maps are now available and have been studied to further inform recommendations for future management on this refuge. Future management of the system should continue to evaluate present conditions of the different habitat types, wildlife populations, soil distribution, and hydrologic flow. Monitoring will be determined primarily by refuge objectives, but some information should be collected that indicate how factors related to ecosystem structure and function are changing, regardless of whether the restoration and management options identified in this report are undertaken. Ultimately, the success in restoring and sustaining communities and ecosystem functions and values at Baca NWR will depend on how well the physical integrity and hydrological processes and events within the refuge can be restored, maintained, and emulated by management actions as well as the relative resiliency of different habitat types. Therefore, monitoring and evaluation of the management strategies employed at Baca NWR must be long enough to account for the spatial and temporal rate of change for different abiotic and biotic characteristics that are altered (Michener and Haeuber 1998). The availability of future water amounts, timing, and type (groundwater vs. surface water source) is a major item that must be carefully monitored and considered for future management of the refuge. Uncertainty exists about the future of some important water issues and the ability of the USFWS to make some system changes because they are not completely under the control of the USFWS. Also, specific techniques for certain management actions, such as controlling introduced plant species and wildlife populations or restoring specific types of native shrub and grassland communities are not entirely known.

Whatever future management actions occur on Baca NWR, activities should be done in an adaptive management framework where: 1) predictions about community response and water issues are made (e.g., decreased greasewood or rabbitbrush shrub dominated areas on alluvial fans) relative to specific management actions (e.g., restoration of grasslands) in specific locations or communities (e.g., loamy sand or sandy loam soils); and then 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action. Information and monitoring needs for Baca NWR related to the hydrogeomorphic information evaluated in this report are identified below:

GROUND AND SURFACE WATER QUALITY AND QUANTITY

The recent draft Water Resources Inventory Assessment (WRIA) for Baca NWR (Striffler 2013) identified several important future monitoring and information needs related to restoration of water quality and quantity including:

- Careful monitoring and reporting of water use and ecosystem benefits. This monitoring will require updating well-meter calibrations, documenting historic points of diversion, restoring and maintaining points of water diversion, and use of appropriated water rights.
- Install in-stream flow meters to better measure flows not only near the top of the alluvial fan but as creeks drain into the sump area.
- Initiate a baseline water monitoring program to document changes in water quality and quantity over time in surface and groundwater resources.
- Conduct routine monitoring of water quality and contaminant issues in relation to water source and routing. Regular monitoring of surface water, groundwater, and soil salinity in key reference locations related to HGM-determined communities should be established (e.g. determine changes as water tables decrease in and around the Closed Basin Project).
- Continue to participate in SLV water monitoring and management activities and determine potential effect of various climate change scenarios.

RESTORING NATURAL WATER FLOW PATTERNS AND WATER REGIMES

This report identifies several potential physical and management changes that could help restore natural topography, water flow patterns and pathways, and natural water regimes at Baca NWR. These changes include restoring more natural surface water flow through natural drainages across the floodplain in a sheetflow manner and managing playa lakes for more natural spring-flooded seasonal flooding regimes. Further, restoring inter-annual dynamics of flooding and drying in playa lakes managed for seasonal water regimes and shallowly flooded wet meadows is desired. The following monitoring will be important to understanding effects of these changes if implemented:

- Continue to evaluate current water-control infrastructure to determine if current and future water management needs (e.g. capacity and placement) are being met or if changes to the system are warranted.
- Evaluate current hydrologic flow patterns in relation to HGM recommendations to restore some historical flow through natural channels.
- Evaluate surface and groundwater interactions and flow. Install peziometers to document fluctuations in the water table in relation to each of the different habitat types being restored and in relation to the various well types on the refuge.
- Document the timing, duration, and extent of surface water across habitat types. Observations of how water flows through current water-control structures in, for example, wet meadow habitats will help guide the modification of existing structures and the placement of new ones in appropriate locations, both vertically and horizontally, to distribute water in a sheetflow pattern without causing head-cuts or other water delivery-induced impacts to the system (Zeedyk 1996).
- Monitor groundwater changes within features such as dunes or inter-dunal swales where revegetation activities occur, such as sagebrush or grass species.
- Document changes in timing and duration of water discharge or recharge in various wetlands after water has been applied.

LONG-TERM CHANGES IN VEGETATION AND ANIMAL COMMUNITIES

The availability of historic vegetation information coupled with regularly documenting changes in general and specific vegetation communities is extremely important to understand the long- term changes and management effects on Baca NWR. Also, regular monitoring of at least some select animal species or groups helps define the capability of the Baca NWR ecosystem to supply key resources to, and meet annual cycle requirement of, animals that use the refuge and regional area. Important information and survey/monitoring needs include:

- Continue evaluation of the historical and current presence and extent of sagebrush in upland shrubland areas.
- Identify grasses in pastures and determine if they are cool or warm season grasses to aid in grazing management strategies.
- Continue to map expansion and contraction of various invasive weed species in relation to the different types of management strategies employed.
- Monitor changes in extent of different wetland and upland habitats in relation to timing, duration, periodicity, and source of water resources utilized.
- Document use of different habitat types by elk throughout the year. If restoration of the shrubland occurs, document use of this habitat in relation to elk herbivory that may occur.
- Monitor extent of shrubs in areas being restored to grasslands to determine if/when shrubs decline, in relation to various management strategies employed.
- Document use of various habitat types by elk and other ungulates to determine patterns and changes in routine in relation to different restoration activities that may take place.
- Monitor the occurrence, timing, and habitat use of key migratory and breeding birds, including grassland birds, Neotropical songbirds, secretive marsh birds, waterfowl, and colonial waterbirds.
- If fire is used as a management tool in grasslands or wetlands, document plant composition pre- and post-fire to determine if desired species are responding positively or negatively to this management strategy.
- Monitor vegetation response to grazing strategies. including the rate, timing, and intensity of grazing as well as the type of stock utilized
- Identify the occurrence, distribution, and abundance of amphibians and reptiles in relation to different hydrologic regimes and wetland types.

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